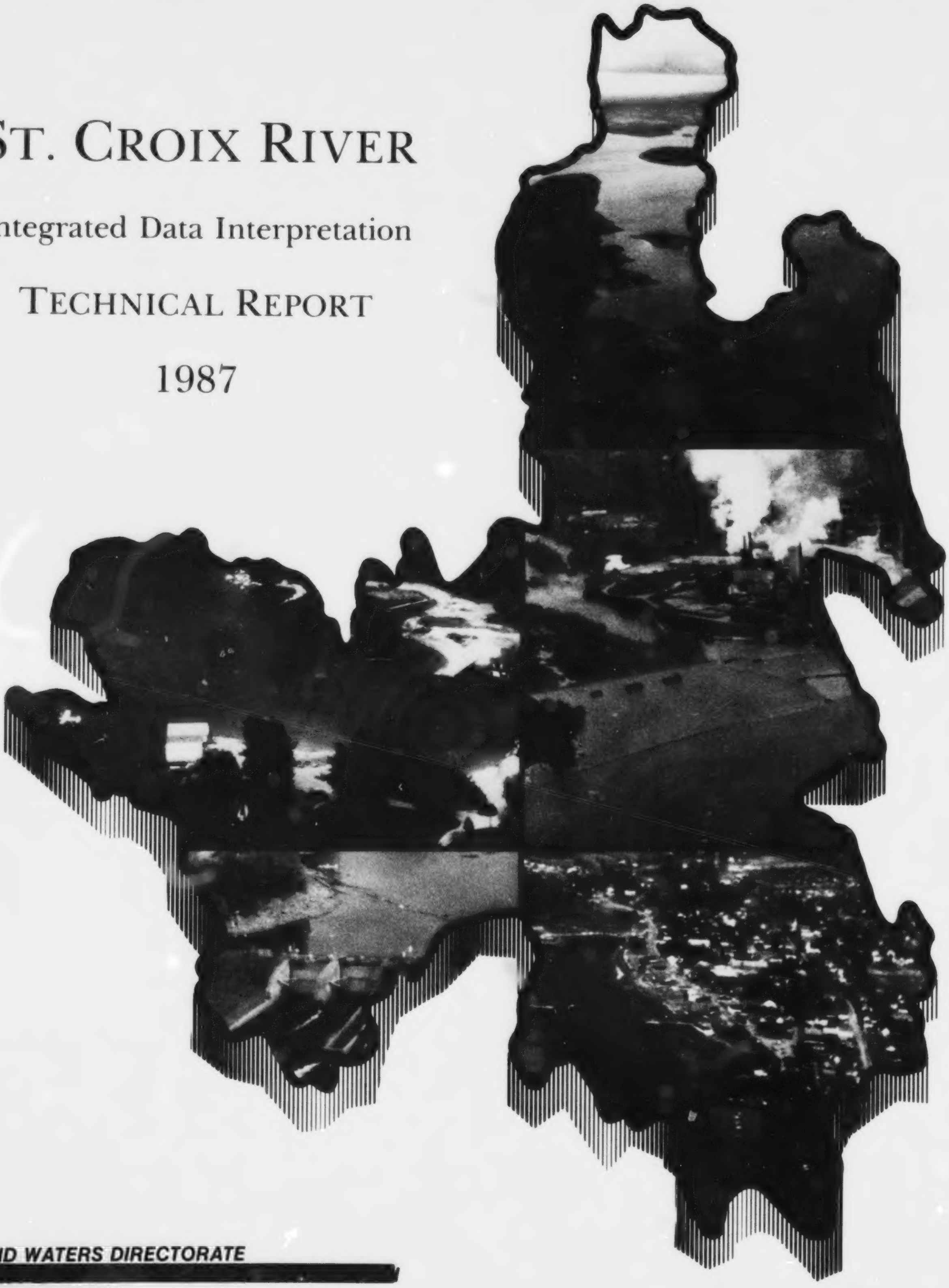
Environment Canada   Environnement Canada
Conservation and Protection   Conservation et Protection

ST. CROIX RIVER

Integrated Data Interpretation

TECHNICAL REPORT

1987



INLAND WATERS DIRECTORATE

ATLANTIC REGION
DARTMOUTH, NOVA SCOTIA

Canada

ST. CROIX RIVER

Integrated Data Interpretation

TECHNICAL REPORT

1987

Prepared by:

St. Croix River Pilot Project Team
Inland Waters Directorate
Conservation & Protection
Atlantic Region
Dartmouth, Nova Scotia

December 1987

PREFACE

This project was initiated by the Inland Waters Directorate, Atlantic Region, partly as an exercise to integrate the three operational units of the Directorate in addressing the total water perspectives of a river basin. As often happens with program work, the focus is entirely on one sector of Water Resources, such as hydrometrics or water quantity, water quality or the resolution of particular issues. Perhaps the penultimate objective of this exercise was to obtain an integrated approach and output from the three participating units to give a more complete picture of the water resource, water issues, and the socio-economics of that basin.

With the benefit of this integrated working experience and updated comprehensive picture of the basin, we are now in a better position to scope out future activities in this international basin. The next important step in the progression of integrated water management is to liaise and coordinate with other federal and provincial agencies who have an interest and mandate in water management in this area. To that end a workshop was held with New Brunswick provincial agencies to assist in defining our roles more clearly. This will assist in providing a much more organized and effective approach for the joint management and resolution of water issues in this basin.

This report includes both the Technical Report and an Overview of Water Management Issues on the St. Croix River which is also published as a separate report.

ACKNOWLEDGEMENTS

This report is the result of the work efforts of a Project Team of specialists assembled from the three Branches of the Inland Waters Directorate. The co-operation and perseverence of these individuals was essential to the successful completion of The St. Croix River Pilot Project.

Mr. Ron Howatt and Ms. Kelly Taylor provided drafting and illustration. The Report cover design was also by Mr. Howatt. Mrs. Dorothy Birks provided typing services with patience through many drafts.

In addition to this, there were many individuals who gave their time to explain their activities in the St. Croix River Basin and also to supply original reports and other data. In particular, the efforts of the following persons are acknowledged:

DERRILL J. COWING	Chief, Maine Office, U.S. Geological Survey
DR. NABIL ELHADI	Director, Water Resources Planning Branch, New Brunswick Department of Municipal Affairs & Environment
STEVEN GROVES	Director, Maine Dept. of Environmental Protection
GEORGE W. PIERCE	Senior Environmental Engineer, Georgia Pacific Corporation, Woodland, Maine

TABLE OF CONTENTS

PAGE

PREFACE (i)

ACKNOWLEDGEMENTS (ii)

TABLE OF CONTENTS (iii)

ST. CROIX RIVER, WATER MANAGEMENT ISSUES, AN OVERVIEW

ST. CROIX RIVER, INTEGRATED DATA INTERPRETATION TECHNICAL REPORT

1.0 INTRODUCTION 1-2

2.0 ST. CROIX RIVER BASIN STUDY AREA 2-2
- 2.1 Location and Climate 2-2
- 2.2 Physiography and Drainage 2-2
- 2.3 Bedrock Geology 2-7
- 2.4 Surficial Geology 2-9
- 2.5 Land Use 2-12
  - 2.5.1 General Description of Land Use in the St. Croix River Basin 2-13
  - 2.5.2 Remote Sensing for Land Use 2-17
- 2.6 Flow and Water Level Regulation 2-19
- 2.7 Water Quality 2-21
- 2.8 Jurisdictional Constraints 2-21
  - 2.8.1 International Laws and Regulations 2-22
  - 2.8.2 Federal Laws/Regulations 2-22
  - 2.8.3 Provincial/State Laws/Regulations 2-24
  - 2.8.4 Local Laws and Regulations 2-26

3.0 SOCIO-ECONOMIC PROFILE 3-2
- 3.1 Introduction 3-2
  - 3.1.1 Historical Perspective 3-2
  - 3.1.2 Current Population 3-3
  - 3.1.3 Economic Activities 3-4
    - 3.1.3.1 Forestry - Forest Products 3-5
    - 3.1.3.2 Power Generation 3-7
    - 3.1.3.3 Agriculture 3-8
    - 3.1.3.4 Recreation 3-9
      - (a) Angling 3-10
      - (b) Canoeing/Kayaking 3-11
      - (c) Camping 3-11
      - (d) Other 3-11
    - 3.1.3.5 Tourism 3-12
    - 3.1.3.6 Food Processing 3-12

TABLE OF CONTENTS (Cont'd)

PAGE

3.1.4 Water Withdrawal and Use 3-12
- 3.1.4.1 Municipal (Domestic) 3-13
  - (a) St. Andrews, New Brunswick 3-13
  - (b) St. Stephen, New Brunswick 3-13
  - (c) McAdam, New Brunswick 3-15
  - (d) Calais, Maine 3-15
  - (e) Baileyville-Woodland, Maine 3-15
- 3.1.4.2 Industrial/Institutional 3-16
- 3.1.4.3 Recreation/Tourism 3-18
- 3.1.4.4 Fisheries 3-21
- 3.1.4.5 Water Use Concerns 3-24

3.1.5 Proposed Economic Development 3-24
- 3.1.5.1 Industrial 3-24
- 3.1.5.2 Hydroelectric Power Development 3-25
- 3.1.5.3 Tourism/Recreation 3-25
- 3.1.5.4 Fisheries 3-26
- 3.1.5.5 Peat Extraction 3-27

3.1.6 Summary 3-28

4.0 SURFACE WATER HYDROLOGY 4-2
- 4.1 Introduction 4-2
- 4.2 St. Croix River Control Regulations 4-2
- 4.3 Availability of Hydrologic Data 4-6
  - 4.3.1 Hydrometric Stations 4-6
  - 4.3.2 Discharge Records 4-6
  - 4.3.3 Water Levels 4-6
  - 4.3.4 Lake Storage Data 4-10
  - 4.3.5 Evaporation Data 4-10
  - 4.3.6 Storage Capacity and Area Relationships 4-11
- 4.4 Preliminary Analyses of Hydrometric Data 4-11
- 4.5 Naturalization of Streamflow Data 4-15
  - 4.5.1 Methodology 4-15
  - 4.5.2 Presentation of Results 4-18
  - 4.5.3 Interpretation of Results 4-18

5.0 SURFACE WATER QUALITY 5-2
- 5.1 Overview of Factors Influencing Present and Past Water Quality 5-2
- 5.2 Overview of Water Quality Guidelines and Objectives 5-3
- 5.3 Water Quality Sampling 5-4
- 5.4 Variations in Water Quality 5-9
  - 5.4.1 Historical Changes in Water Quality 5-9
  - 5.4.2 Water Quality Variation Along the River 5-16
  - 5.4.3 Changes with Flow Discharge 5-24
- 5.5 Focus on Water Quality and Basin Activities 5-28
  - 5.5.1 Pulp and Paper Industry 5-28
  - 5.5.2 Fisheries 5-38
  - 5.5.3 Agriculture 5-39

TABLE OF CONTENTS (Cont'd)

PAGE

6.0 GROUNDWATER HYDROLOGY 6-2
- 6.1 Introduction 6-2
- 6.2 Occurrence and Movement of Groundwater 6-2
- 6.3 Principal Aquifers 6-4
  - 6.3.1 The Bedrock Aquifer 6-4
  - 6.3.2 Effects of Overburden on Bedrock Yields 6-10
  - 6.3.3 Surficial Aquifers 6-11
- 6.4 Water Level Trends and Fluctuations 6-12
- 6.5 Groundwater Quality 6-14
- 6.6 Human Impacts on Groundwater Quality 6-17
  - 6.6.1 Fuel Storage Tanks 6-18
  - 6.6.2 Salt Storage and Highway De-icing 6-19
  - 6.6.3 Septic Systems 6-20
  - 6.6.4 Radioactive Waste Disposal 6-20
  - 6.6.5 Other Sources 6-21
- 6.7 Groundwater Information Sources for New Brunswick and Maine 6-21

REFERENCES R-1

LIST OF FIGURES

PAGE

1.1 Project Team Organization Chart 1-3

2.1 St. Croix River Basin Pilot Project Study Area (Fold-out) 2-3
2.2 Mean Annual Precipitation, 1951-1980 2-4
2.3 Physiographic Regions 2-5
2.4 Bedrock Geology (Generalized) 2-8
2.5 Surficial Geology (Generalized) 2-10
2.6 Typical Stratigraphic Sequence 2-12
2.7 Land Use and Land Cover (fold-out) 2-14
2.8 Land Use in the St. Croix River Basin 2-16
2.9 Agricultural Capability on the Canadian Side of Basin 2-16
2.10 Forest Capability on the Canadian Side of Basin 2-16
2.11 Water Level and Flow Discharge Control Regulations 2-20

3.1 St. Croix River Basin Population 1900-1980 3-3
3.2 Georgia Pacific Corporation Land Holdings (Fold-out) 3-6
3.3 ST. Croix Waterway Recreation Area 3-19
3.4 St. Croix Waterway Joint Advisory Commission Area of Jursidiction 3-20
3.5 Nominated Canadian Heritage Rivers System Designation Area 3-22

4.1 Hydrometric and Water Level Stations 4-8
4.2 St. Croix River Basin Hydrometric Stations - Period of Record 4-9
4.3 Monthly Lake Evaporation St. Croix River Basin 4-12
4.4 Area Capacity Curves for Grand Lake, Spednic Lake, West Grand Lake, Grand Falls Flowage 4-13
4.5 Schematic of St. Croix River Reservoir Systems 4-17
4.6 Comparison of Monthly Runoffs (fold-out) 4-19
4.7 Mean Monthly Runoff 4-20
4.8 Annual Mean Runoff 4-21
4.9 Mean Monthly Total Precipitation 4-22
4.10 Annual Total Precipitation 4-23

5.1 Period of Record - St. Croix River Water Quality Sampling Stations 5-7
5.2 1986 Water Quality Sampling Stations 5-8
5.3 Box and Whisker Plot 5-10
5.4 Sulfate (mg/l) in St. Croix River at St. Croix 5-11
5.5 Magnesium (mg/l) in St. Croix River at St. Croix 5-11
5.6 Sodium (mg/l) in St. Croix River at St. Croix 5-11
5.7 Calcium (mg/l)in St. Croix River at St. Croix 5-12
5.8 Total Alkalinity (mg/l as $CaCO_3$) in St. Croix River at St. Croix 5-12
5.9 Specific Conductance (us/cm) of St. Croix River at St. Croix 5-12
5.10 Sulfate (mg/l) in St. Croix River at Milltown 5-14

LIST OF FIGURES (Cont'd)

PAGE

5.11 Magnesium (mg/l) in St. Croix River at Milltown 5-14
5.12 Sodium (mg/l) in St. Croix River at Milltown 5-14
5.13 Chloride (mg/l) in St. Croix River at Milltown 5-15
5.14 Calcium (mg/l) in St. Croix River at Milltown 5-15
5.15 Total Alkalinity (mg/l as $CaCO_3$) in St. Croix River at Milltown 5-15
5.16 Specific Conductance (us/cm) of St. Croix River at Milltown 5-17
5.17 Minimum, Maximum and Mean Dissolved Oxygen (mg/l) for Month of July, for period 1975 to 1984 5-17
5.18 Minimum, Maximum and Mean Dissolved Oxygen for Month of August, for period 1975 to 1984 5-17
5.19 Dissolved Oxygen (mg/L) in St. Croix River at Milltown 5-18
5.20 Dissolved Oxygen (% Saturation) in St. Croix River at Milltown 5-18
5.21 Variation in Sum of Constituents at Six Sampling Stations 5-22
5.22 Major Ion Chemistry of St. Croix River 5-22
5.23 Variation in Water Colour at Six Sampling Stations 5-23
5.24 Variation in Dissolved Organic Carbon at Six Sampling Stations 5-23
5.25 Comparison of Discharge and Specific Conductance 5-26
5.26 Relationship between Discharge and Milltown AWQM Specific Conductance Measurements 5-26
5.27 Daily Mean, Maximum and Minimum Dissolved Oxygen 5-27
5.28 Dissolved Oxygen in St. Croix River (mg/l) 5-29
5.29 Dissolved Oxygen (% Saturation) in the St. Croix River 5-29
5.30 pH at Six Sampling Stations in the St. Croix River 5-31
5.31 Extractable Aluminum 5-31
5.32 Extractable Cadmium 5-32
5.33 Extractable Copper 5-32
5.34 Extractable Iron 5-33
5-35 Extractable Lead 5-33
5.36 Extractable Mercury 5-35
5-37 Non-Filterable Residue 5-35
5-38 Variation in Selected Major Ion Concentrations Over a 13 Day Period 5-37
5-39 Variation in Specific Conductance and Mean Daily Discharge over a 13 Day Period 5-37

6.1 Paths of Groundwater Movement 6-3
6.2 Principal Aquifers 6-6
6.3 Yield of Bedrock Wells in New Brunswick and Maine 6-7
6.4 Number of Water Bearing Fractures Intersected by Bedrock Wells 6-8

LIST OF FIGURES (Cont'd)

PAGE

6.5 Depth in Bedrock to the First Water Bearing Fracture 6-8
6.6 Decrease in Well Yields with Depth in Crystalline Rocks 6-8
6.7 Change in the Number of Water Bearing Fractures with Increasing Depth into Bedrock 6-9
6.8 Distribution of Well Yields with Respect to Topographic Position 6-10
6.9 Effect of Overburden Type and Thickness on the Yield of Bedrock Wells Drilled into the Underlying Bedrock 6-11
6.10 Water Level Records of 3 Kinds of Bedrock Wells 6-13
6.11 Area of the St. Croix Basin Covered by the Sea at the Close of the Last Glacial Period 6-16
6.12 Occurrence and Movement of Groundwater Typical of the Sediments and Fractured Bedrock of the St. Croix River Basin 6-17

LIST OF TABLES

PAGE

2.1 Land Use in the St. Croix River Watershed 2-13

3.1 Incorporated Municipalities with Populations of 1,000+ People 3-3
3.2 Maine-New Brunswick Populations in the St. Croix River Basin 3-4
3.3 Hydroelectric Generating Facilities 1985 3-7
3.4 Water Use/Withdrawal 3-14
3.5 Sewage Treatment 3-14

4.1 St. Croix River Basin Hydrometric Stations 4-7
4.2 Discharge and Water Level Statistics at Selected Locations in the St. Croix River Basin - Period 1969 to 1985 4-14

5.1 Selected Water Quality Guidelines and Objectives for Protection of Freshwater Aquatic Life 5-4
5.2 NAQUADAT Numbers and Site Descriptions of all Sampling Stations on the St. Croix River 5-6
5.3 Changes in Mill Operational Procedures and Selected Water Quality Parameters Over Time 5-13
5.4 1986 St. Croix River Monitoring Data 5-20
5.5 Measurements of Selected Water Quality Parameters at Three Stations at Baring 5-24
5.6 Application of Guthion 5-40

6.1 Estimated Groundwater Use in New Brunswick and Maine 6-2
6.2 Aquifer and Well Characteristics of Crystalline Bedrock and Surficial Deposits in New Brunswick and Maine 6-5
6.3 Hydrochemistry of Selected Wells 6-15

ST. CROIX RIVER

Water Management Issues

AN OVERVIEW

1988

Prepared by:

Inland Waters Directorate
Conservation & Protection
Atlantic Region
Dartmouth, Nova Scotia

December 1988

TABLE OF CONTENTS

INTRODUCTION 1

THE ST. CROIX RIVER BASIN 1

ISSUES, RIVER USERS AND SPECIAL INTERESTS 3

WATER QUALITY 5

WATER QUANTITY 14

CONFLICTING USES 19

RECREATIONAL DEVELOPMENT 21

SUMMARY 23

AFTERWORD 24

INTRODUCTION

The St. Croix River Basin, situated along the Maine-New Brunswick border, has had a history of conflicting water use demands. Hydroelectric power production, forest products processing, pollution abatement and fisheries and recreational uses demand both adequate lake storage and downstream maintenance flows. This illustrates the major water management problem in the basin.

In 1986, the Inland Waters Directorate of Environment Canada initiated a study of the St. Croix River Basin to demonstrate the integration and interpretation of available data. It was felt such a study could contribute information useful to the management of the water resources of the basin, and help raise the level of public awareness of important issues related to the St. Croix River.

As a result of this work, a Technical Report was completed in 1987. It was foreseen that, because of the comprehensive scope of the task at hand, the technical report would be a lengthy and detailed document. Therefore, it was decided that an overview report would be of benefit to interpret and integrate the key findings of the project which would be useful to water managers and to others with a strong interest in the water resources of the basin. The following is that overview report.

THE ST. CROIX RIVER BASIN

The St. Croix River Basin (see Figure 1) covers an area of 4230 km^2 straddling the Canada and United States border between southwestern New Brunswick, and southeastern Maine. The basin is bounded on the north by the Saint John River Basin, on the west by the Penobscot River Basin, and the south and east by coastal streams.

The basin has a continental climate characterized by cold winters and warm summers. The mean annual precipitation for the Basin is 1140 mm, with fairly uniform distribution throughout the year.

The basin has the shape of an irregular "Y" with two principal chains of lakes - the northern group along the international boundary, and the western group in The State of Maine - both of which join at Kellyland along the main stem of the river. The river then flows southeasterly along the international boundary, becoming tidal at St. Stephen and emptying into Passamaquoddy Bay.

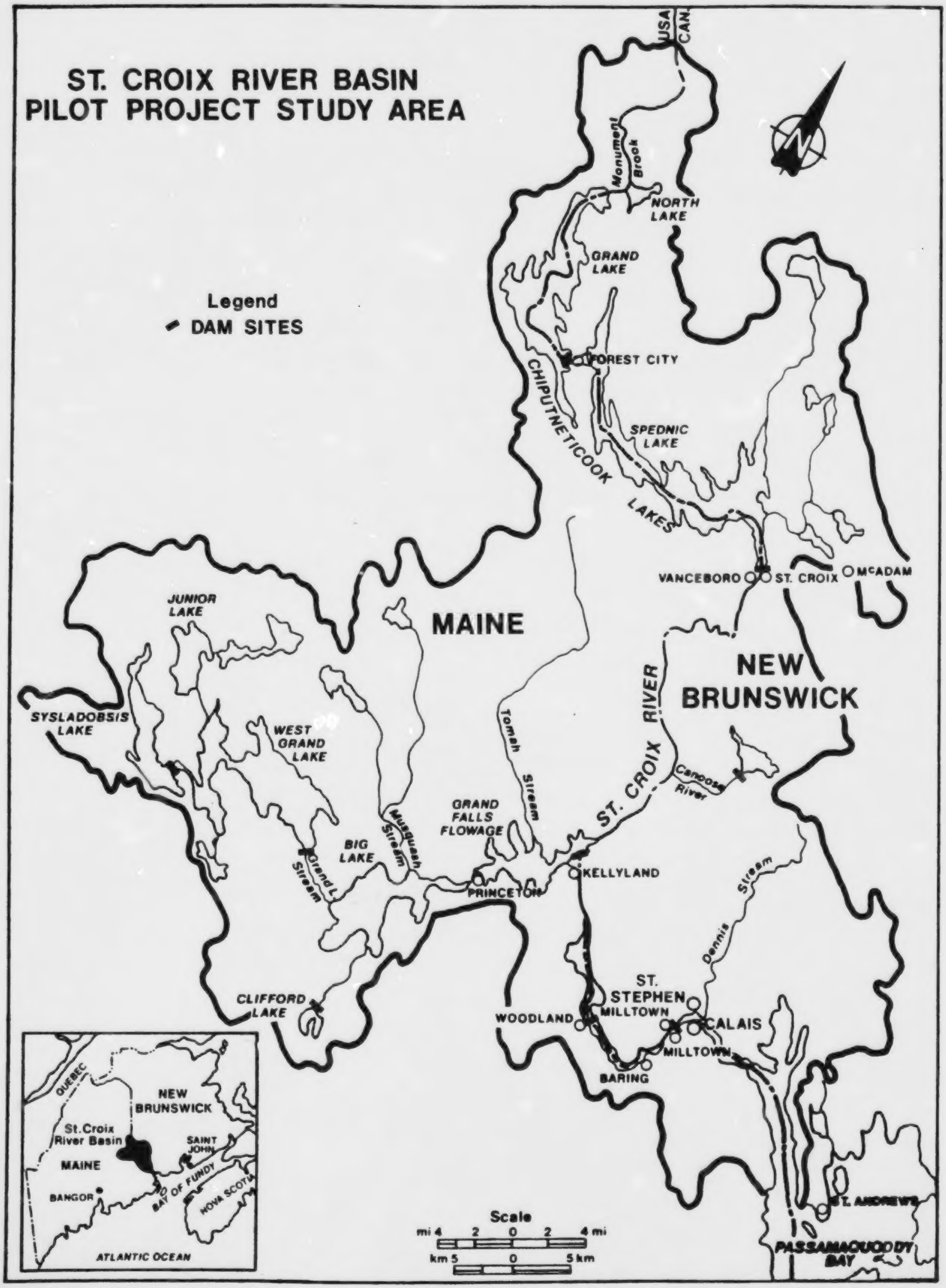

ST. CROIX RIVER BASIN
PILOT PROJECT STUDY AREA
Legend
DAM SITES
USA
CAN.
Monument Brook
NORTH LAKE
GRAND LAKE
FOREST CITY
CHIPUTNETICOOK LAKES
SPEDNIC LAKE
VANCEBORO
ST. CROIX
McADAM
JUNIOR LAKE
MAINE
NEW BRUNSWICK
SYSLADOBSIS LAKE
WEST GRAND LAKE
Tomah Stream
ST. CROIX RIVER
Canoose River
GRAND FALLS FLOWAGE
Musquash Stream
BIG LAKE
Grand L. Stream
PRINCETON
KELLYLAND
Dennis Stream
ST. STEPHEN
MILLTOWN
WOODLAND
CALAIS
MILLTOWN
BARING
CLIFFORD LAKE
ST. ANDREWS
PASSAMAQUODDY BAY
QUEBEC
NEW BRUNSWICK
St.Croix River Basin
MAINE
SAINT JOHN
BANGOR
BAY OF FUNDY
NOVA SCOTIA
ATLANTIC OCEAN
Scale
mi 4 2 0 2 4 mi
km 5 0 5 km

Figure 1

The headwaters of the St. Croix River begin with Monument Brook which flows into North Lake, then into Grand Lake (known as East Grand Lake in the U.S.), passing through Forest City and into Spednic Lake (spelled Spednik Lake in the U.S.), forming the Chiputneticook Lakes System or the northern group.

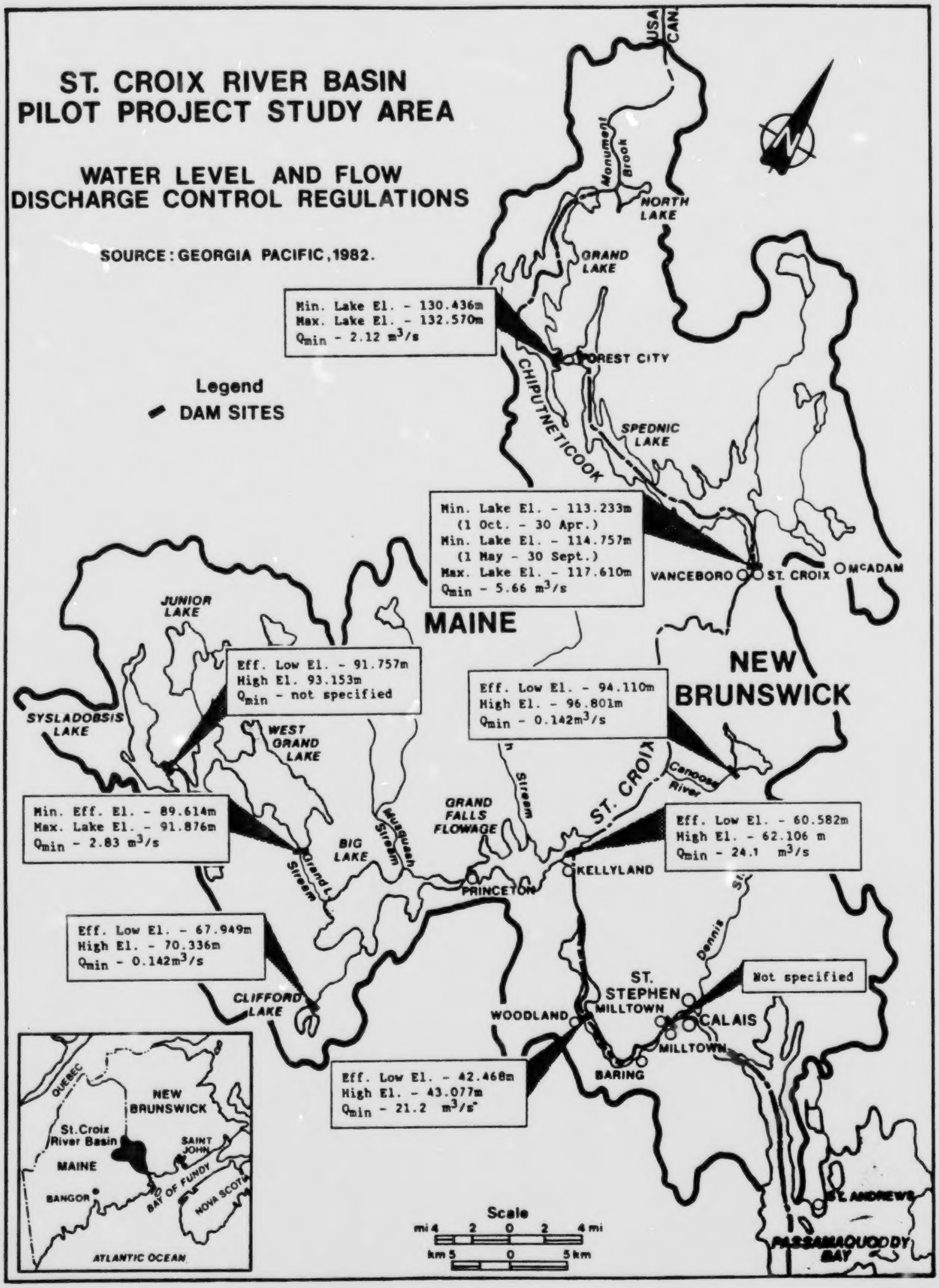
In the western group, Sysladobsis Lake, Junior Lake, West Grand Lake, Big Lake and others all contribute to the Grand Falls Flowage, which enters the river at Kellyland. Of far lesser importance there are adjoining watersheds in Maine which probably contribute some flow to the St. Croix River, such as Meddybemps Lake, which can flow into the St. Croix River under high level conditions.

Land use in the St. Croix River Basin is predominantly (80%) forestry related and has been since the late 1800s. This historic pattern is similar on both sides of the Canada/U.S. border. Agriculture is a distant second land use, occupying about 10% of the basin on the Canadian side and somewhat less on the American side. Agricultural land use has changed little over the last few decades, but some land is being brought back into production. Blueberry production is expanding in the Basin.

The other 10% of land uses include urban and outdoor recreation uses, and these have remained stable, but more emphasis can be expected in the future on recreational activities.

ISSUES, RIVER USERS AND SPECIAL INTERESTS

It is evident that there are a number of competing, if not conflicting uses made of the St. Croix River. Georgia-Pacific Corporation owns approximately 75% of the watershed which reflects forestry land use activities, and Georgia-Pacific also regulates the watershed through various reservoirs and control dams (Figure 2). These dams are operated in accordance with control regulations, but there is no single regulatory or co-ordinating body with the mandate to carry out water resource management of the entire basin. As a result there is no single body to resolve conflicts, except for the International Joint Commission (I.J.C.) for disputes in the waters along the international boundary. Water levels and maintenance flow from regulated lakes along the Canada-U.S. border are subject to requirements set and enforced by the I.J.C. through their Board of Control. The I.J.C. Advisory Board on Pollution Control further established water quality objectives for dissolved oxygen and pH.



ST. CROIX RIVER BASIN
PILOT PROJECT STUDY AREA

WATER LEVEL AND FLOW
DISCHARGE CONTROL REGULATIONS

SOURCE: GEORGIA PACIFIC, 1982.

Legend
DAM SITES

Min. Lake El. - 130.436m
Max. Lake El. - 132.570m
Q_{min} - 2.12 m^3/s

Min. Lake El. - 113.233m
(1 Oct. - 30 Apr.)
Min. Lake El. - 114.757m
(1 May - 30 Sept.)
Max. Lake El. - 117.610m
Q_{min} - 5.66 m^3/s

Eff. Low El. - 91.757m
High El. 93.153m
Q_{min} - not specified

Eff. Low El. - 94.110m
High El. - 96.801m
Q_{min} - 0.142m^3/s

Min. Eff. El. - 89.614m
Max. Lake El. - 91.876m
Q_{min} - 2.83 m^3/s

Eff. Low El. - 60.582m
High El. - 62.106 m
Q_{min} - 24.1 m^3/s

Eff. Low El. - 67.949m
High El. - 70.336m
Q_{min} - 0.142m^3/s

Not specified

Eff. Low El. - 42.468m
High El. - 43.077m
Q_{min} - 21.2 m^3/s

USA
CAN.
Monument Brook
NORTH LAKE
GRAND LAKE
FOREST CITY
CHIPUTNETICOOK
SPEDNIC LAKE
VANCEBORO
ST. CROIX
McADAM
MAINE
NEW BRUNSWICK
JUNIOR LAKE
SYSLADOBSIS LAKE
WEST GRAND LAKE
GRAND FALLS FLOWAGE
Stream
ST. CROIX
Canoose River
Musquash Stream
Grand L. Stream
BIG LAKE
PRINCETON
KELLYLAND
Dennis St.
CLIFFORD LAKE
WOODLAND
ST. STEPHEN
MILLTOWN
CALAIS
MILLTOWN
BARING
ST. ANDREWS
PASSAMAQUODDY BAY
QUEBEC
NEW BRUNSWICK
St. Croix River Basin
MAINE
SAINT JOHN
BAY OF FUNDY
NOVA SCOTIA
BANGOR
ATLANTIC OCEAN
Scale
mi 4 2 0 2 4 mi
km 5 0 5 km

Figure 2

Georgia-Pacific utilizes water for hydro-electric power production and in their pulp and paper processes, and also for effluent disposal of mill wastes at Woodland, Maine. The New Brunswick Electric Power Commission (N.B. Power) also generates hydro-electric power at Milltown but they essentially use whatever run-of-the-river flow is available.

The designation of part of the river system as the St. Croix Recreational Waterway Area (Figure 3), and as a Heritage River (Figure 4) should lead to more emphasis on tourism and recreation in the basin. Current recreational activities include canoeing, kayaking, fishing and the use of the lakes and waterways as cottage sites. The maintenance of lake levels, in particular on Spednic Lake, is an issue that has been raised several times over the years. Even though Georgia-Pacific has had a good record of meeting the required water levels and maintenance flows, the question of changing the rule curve and required lake levels has been raised. Changing of operating rules to provide higher lake levels could lead to problems in maintaining specified maintenance flows below the dam, as well as reducing hydroelectric power generation during critical periods. There has also been pressure to increase maintenance flows below Woodland. This in effect would conflict with the wishes of Spednic Lake residents as water levels would have to be drawn down to meet this requirement. However, since 60% of the watershed is in the State of Maine, it is conceivable that more water could be drawn from the U.S. to meet the downstream requirements. Thus, an international study would have to be initiated to address these issues.

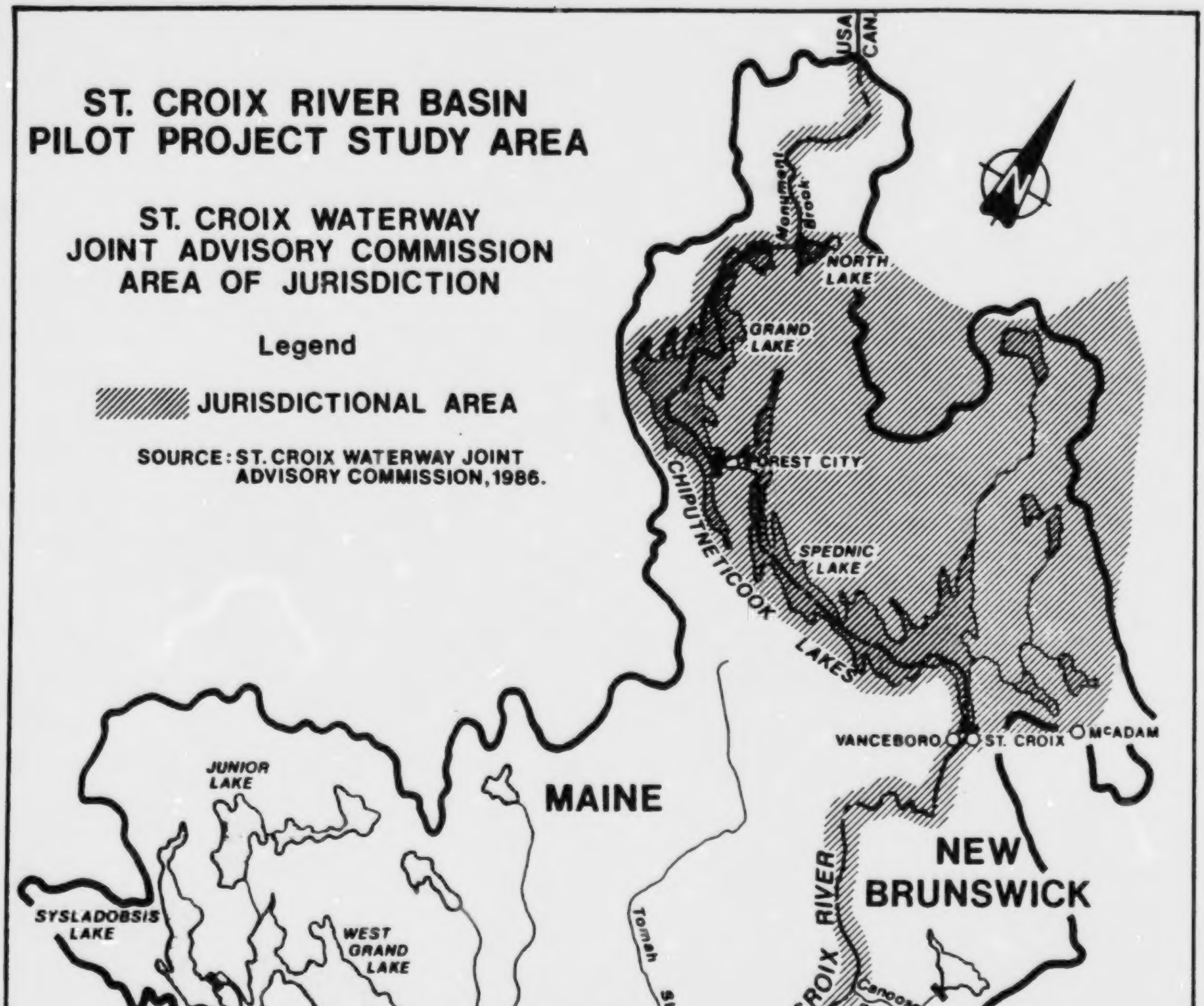
Other issues such as water withdrawal for domestic consumption are not perceived as a problem, but the use of the river for sewage effluent discharge has been identified by Environment Canada as a source of fecal coliform contamination in shellfish in the estuary.

The following is a discussion of the principal areas of concern that will be presented in the form of answers to questions to illustrate the inter-relationships involved.

WATER QUALITY

Are there trends occurring in water quality over time?

Fresh water quality in the upper reaches of the river above Woodland is relatively "pristine" and reflects the geology of the area and the chemistry of precipitation. It remains



ST. CROIX RIVER BASIN PILOT PROJECT STUDY AREA

ST. CROIX WATERWAY JOINT ADVISORY COMMISSION AREA OF JURISDICTION

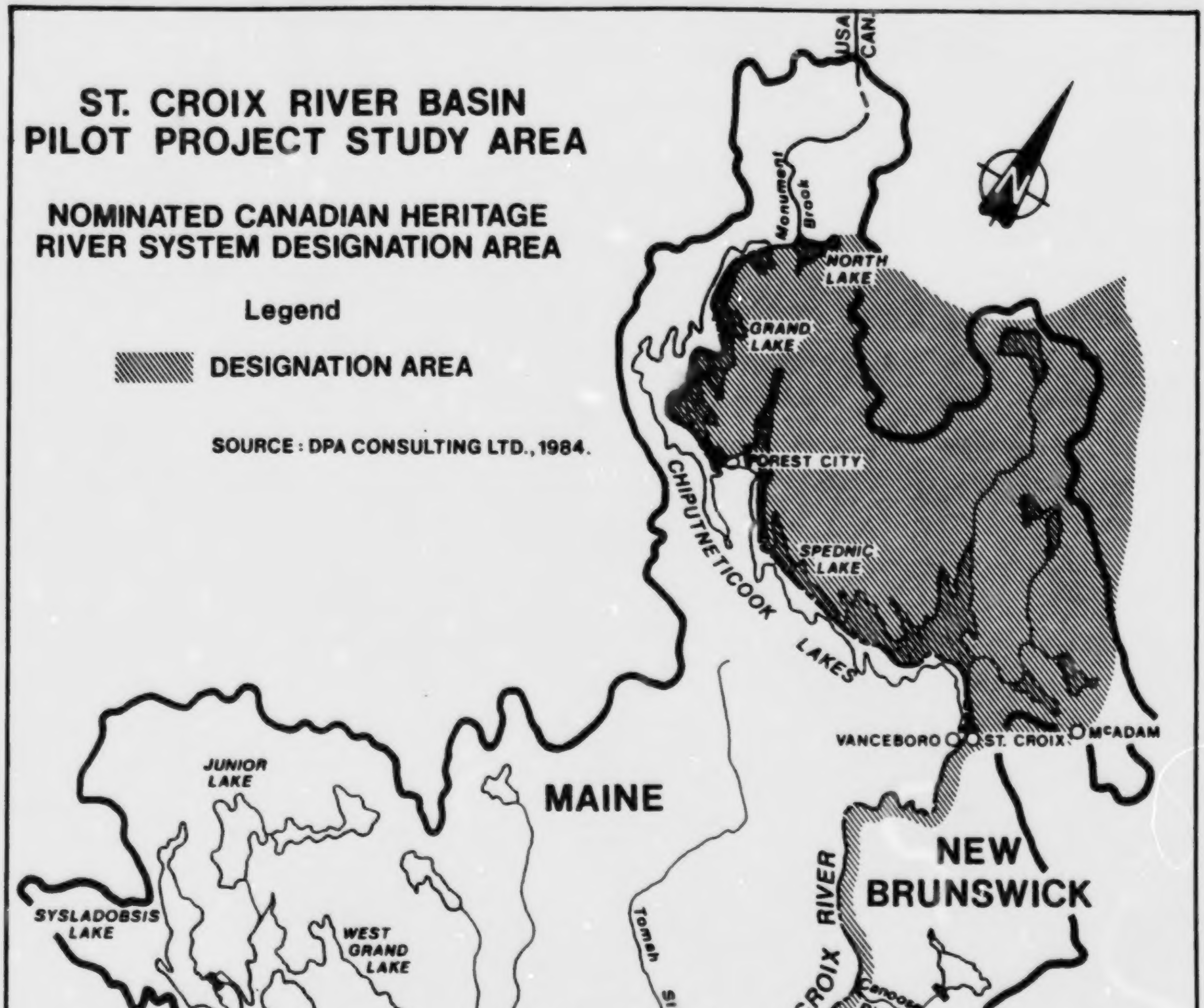
Legend

▨ JURISDICTIONAL AREA

SOURCE: ST. CROIX WATERWAY JOINT ADVISORY COMMISSION, 1986.

USA
CAN.
Monument Brook
NORTH LAKE
GRAND LAKE
FOREST CITY
CHIPUTNETICOOK LAKES
SPEDNIC LAKE
VANCEBORO
ST. CROIX
McADAM
MAINE
NEW BRUNSWICK
JUNIOR LAKE
SYSLADOBSIS LAKE
WEST GRAND LAKE
Tomah Stream
ST. CROIX RIVER
Canoose River
GRAND FALLS FLOWAGE
Musquash Stream
BIG LAKE
Grand L. Stream
PRINCETON
KELLYLAND
Dennis Stream
CLIFFORD LAKE
ST. STEPHEN
WOODLAND
MILLTOWN
CALAIS
MILLTOWN
BARING
ST. ANDREWS
PASSAMAQUODDY BAY
Scale
mi 4 2 0 2 4 mi
km 5 0 5 km
QUEBEC
NEW BRUNSWICK
St. Croix River Basin
MAINE
SAINT JOHN
BANGOR
BAY OF FUNDY
NOVA SCOTIA
ATLANTIC OCEAN

Figure 3



ST. CROIX RIVER BASIN PILOT PROJECT STUDY AREA

NOMINATED CANADIAN HERITAGE RIVER SYSTEM DESIGNATION AREA

Legend

▨ DESIGNATION AREA

SOURCE : DPA CONSULTING LTD., 1984.

USA
CAN
Monument Brook
NORTH LAKE
GRAND LAKE
FOREST CITY
CHIPUTNETICOOK LAKES
SPEDNIC LAKE
VANCEBORO
ST. CROIX
McADAM
MAINE
NEW BRUNSWICK
ST. CROIX RIVER
JUNIOR LAKE
SYSLADOBSIS LAKE
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Tomah Stream
Canoose River
GRAND FALLS FLOWAGE
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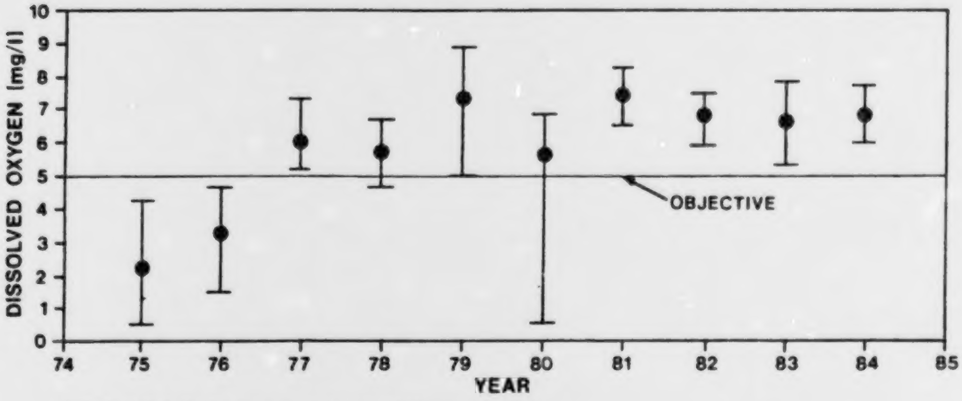
Grand L. Stream
PRINCETON
KELLYLAND
Dennis Stream
ST. STEPHEN
MILLTOWN
WOODLAND
CALAIS
MILLTOWN
BARING
CLIFFORD LAKE
ST. ANDREWS
PASSAMAQUODDY BAY
QUEBEC
NEW BRUNSWICK
St. Croix River Basin
MAINE
SAINT JOHN
BAY OF FUNDY
NOVA SCOTIA
BANGOR
ATLANTIC OCEAN
Scale
mi 4 2 0 2 4 mi
km 5 0 5 km

Figure 4

substantially unaffected by man's activities over time, with the possible exception of the impact of acid rain.

Trends in fresh water quality below Woodland are directly related to the discharge of industrial effluent from the Georgia-Pacific mill. Pulp and paper processing started early in this century. Subsequently the river downstream, was abandoned as a source of drinking water. Over the years the mill has undergone process changes and has instituted improved effluent treatment systems. Prior to 1978, summer dissolved oxygen levels were characteristically less than 3.0 mg/l, but with the introduction of secondary treatment in 1978, combined with regulating discharge and effluent composition, river oxygen demand was lowered in the 14 km between Woodland and Milltown. As a result, the dissolved oxygen regime at Milltown has greatly improved. In recent years, dissolved oxygen has met the water quality objective of 5.0 mg/l or 60% saturation (Figure 5), and this condition has permitted the reintroduction of Atlantic Salmon to the river.



NOTE: U.S.G.S. Published Data for Milltown AWQM.

Figure 5 Minimum, Maximum and Dissolved Oxygen (mg/l)
Month of August by Year

Fecal coliform contamination has closed the estuary area to shellfish harvesting. The last major survey in 1982 suggests that bacteriological water quality has improved since earlier surveys. Recent in-plant improvements at Ocean Maid Foods and chlorination at the St. Stephen sewage treatment plant may have a positive impact on the fecal coliform levels in the estuary.

Are the historic records adequate to illustrate trends?

Historic water quality data are available from the 1950s to the present at some sites, but data at individual sites in the upper basin are somewhat fragmented. However, taking into consideration the similarity between sites, the composite data base is adequate to illustrate trends over time and over distance.

The most comprehensive data set has been collected at Milltown through the use of an automatic water quality monitor and grab sampling. However, it must be realized that the water quality trends at this site are primarily directly related to the effluent discharge at Woodland. Grab samples are useful for the characterization of water quality above Woodland, provided they are taken over a range of flow conditions, while the automatic water quality monitor is necessary to ensure that water quality objectives are met below Woodland.

Bacteriological data are available from four surveys of shellfish-growing areas in the St. Croix River estuary since 1963. Although this is probably not enough data to determine continuous trends, it does provide an indication as to whether the area is being degraded or is improving.

Can water quality changes be detected as you progress downstream?

Water quality upstream of the Woodland Pulp and Paper Plant reflects the geology of the area and is essentially "natural". The waters are soft, being calcium-bicarbonate based. The sum of constituents, a measure of the total ionic strength of the water, averages 20 ppm above Woodland, increases to over 1600 ppm below Woodland and settles down to less than 60 ppm at Milltown. (Figure 6)

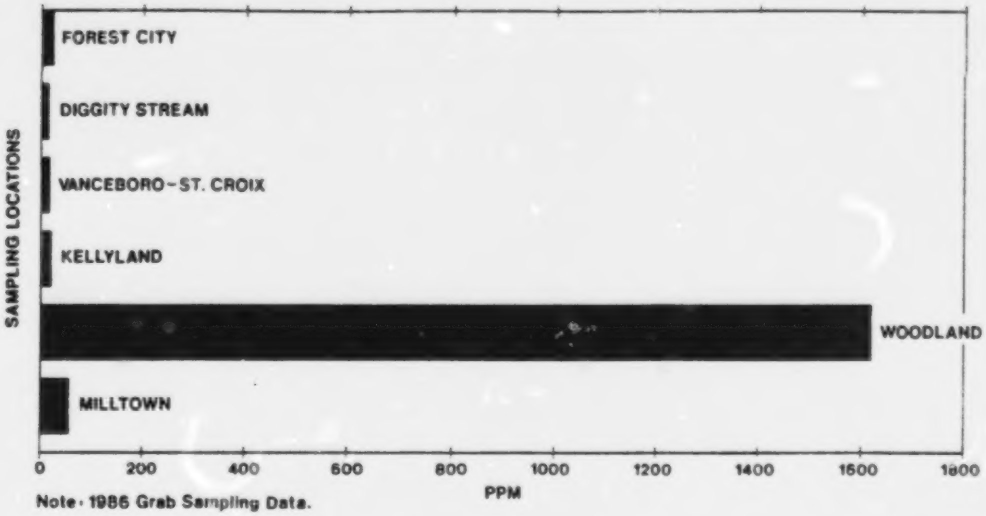


Figure 6 Variation in Sum of Constituents from Upstream to Downstream

The chemistry of the water changes from a calcium-bicarbonate base in the upper basin to a sodium chloride base below Woodland, reflecting the effluent characteristics of the Georgia-Pacific pulp and paper plant. (Figure 7)

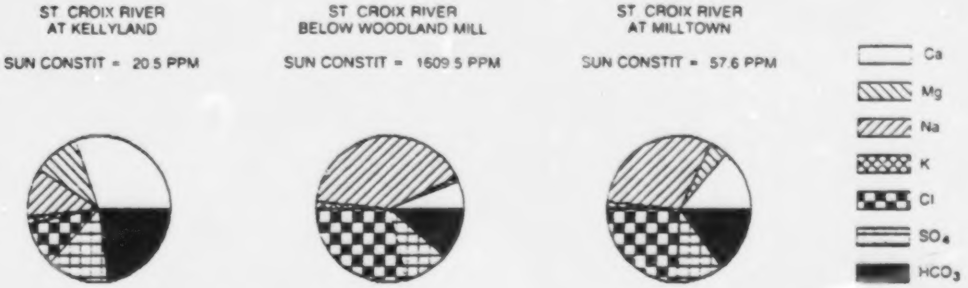
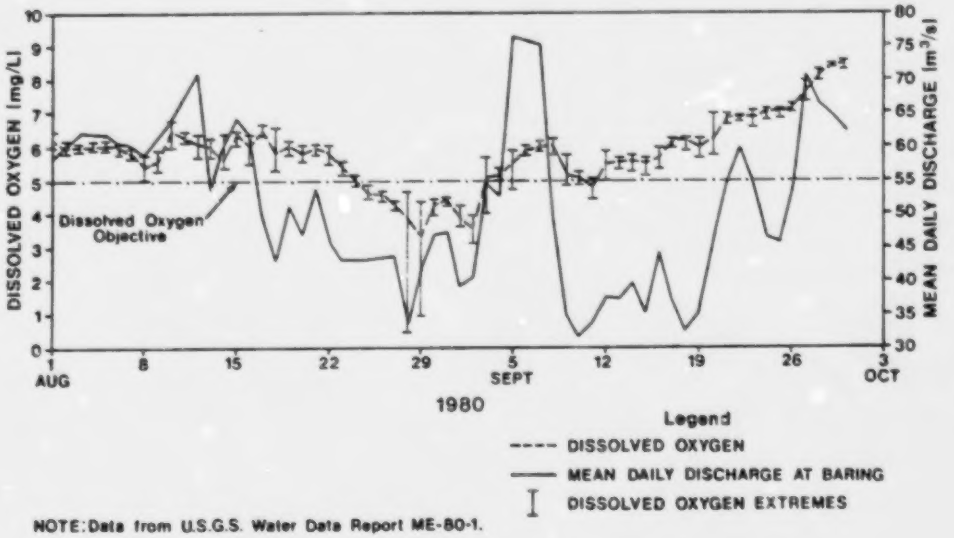


Figure 7 Major Ion Chemistry

How does water quality change when flow discharge changes?

Environment Canada has developed a nomographic model which relates specific conductance, oxygen saturation and river discharge. The model indicates that objective levels for dissolved oxygen can be met or exceeded provided minimum river discharges are maintained. This further suggests that there is a threshold of discharge and, if it is maintained, there should be no problem with dissolved oxygen objectives as long as the flow is maintained at levels above that required by the International Joint Commission. Dissolved oxygen is essential to fish life and an objective 5 mg/l has been established.

The strength and importance of the relationship between dissolved oxygen and discharge is illustrated by an event in August 1980. An equipment malfunction caused the flow to drop well below the minimum mean daily discharge of 21.2 m^3/s (750 cfs) for several hours. During this period, the treated effluent continued to be discharged undiminished. Without sufficient river dilution, the residual Biological Oxygen Demand (B.O.D.) in the wastes nearly exhausted the available dissolved oxygen (0.5 mg/l) (Figure 8) and resulted in a fish kill, even though the average flow for the day shows no violation.



NOTE: Data from U.S.G.S. Water Data Report ME-80-1.

Figure 8 Dissolved Oxygen - Mean Daily Discharge

An increase in maintenance flow of 25 to 30% would probably have an overall positive effect on the water quality below Woodland as a result of dilution, however, the nomographic model suggests that the minimum maintenance flows, if they were required on an instantaneous basis, could be reduced without affecting oxygen saturation, except at high temperatures which are unlikely to occur in the river.

Is water quality adequate for fisheries, recreation, swimming, canoeing and cottaging, and are the trends in water quality affecting these activities?

The water quality meets the guidelines for the protection of freshwater aquatic life at all sites except the Woodland station, which characterizes the effluent before full dilution with river water. The effluent travels in a plume along the U.S. shoreline and gradually diffuses into the water column, but water quality for salmon passage remains adequate along the Canadian side of the river.

Summer dissolved oxygen levels, which had been perennially too low to support fish prior to 1978, have improved to allow the reintroduction of Atlantic Salmon to the river in 1980.

In general, recreation, swimming, canoeing and cottaging activities require water quality that meets the guidelines for recreational waters. The Canadian Water Quality Guidelines, prepared by the Canadian Council of Resource and Environment Ministers, (CCREM 1987) divide these guidelines into two groups: direct contact with the water (swimming), and less frequent contact with the water (canoeing, etc.). Guidelines for swimming include micro-biological (health related), nuisance (vegetation), and physical and chemical (aesthetics, clarity, etc.). Guidelines for non-swimming include nuisance, visual and aesthetics. Most contact recreational activities probably take place in the headwater lakes and estuary. The presence of fecal coliform contamination in these headwaters is unlikely, and most certainly would be very localized.

In four surveys since 1963, there has been a systematic 10-fold reduction in total coliform levels in this reach below St. Stephen. The decline in total coliform values has been attributed to the installation of the sewage treatment system in St. Stephen. A comparison of limited fecal coliform data indicated that median levels obtained in 1982 were lower than values determined in 1970 and 1972 surveys, but they are still above limits established by the guidelines.

In other words, except for the localized area of the effluent plume prior to mixing, water quality is adequate for fisheries below Woodland. Fish that pass through or remain in the waters above Woodland generally encounter water quality that exceeds the guidelines for the protection of freshwater aquatic life.

Other activities, such as recreation, swimming, canoeing and cottaging, can be carried out, utilizing good quality water above Woodland. In other words, water quality above Woodland is adequate for these activities. On the other hand, water quality below Woodland does not generally meet the requirements of the guidelines for recreational waters for direct contact or for less frequent contact with the water.

Is water quality affected by land use, and if so, what are the key influences?

Land use in the basin, such as forestry operations and agriculture, have had no measureable impact on the St. Croix River. Considering land use in a very broad sense, the Georgia-Pacific mill operation at Woodland has the greatest impact on water quality as mill effluent discharge is responsible for increases in colour, nutrients, dissolved organic carbons and aluminum. The highly organic nature of Kraft effluent and resultant oxygen demand are the principal causes of dissolved oxygen depletion in the St. Croix River at Milltown.

The waters in Oak Bay and Waweig River are subjected to fecal contamination from landwash and cottages along the shore resulting in closure of this area to shellfish harvesting.

In other words the processing of forest products and the resulting effluent has the major impact on water quality.

Can models be developed to manage water quality in the River?

Predictive oxygen models have been developed using Biological Oxygen Demand (BOD) loadings, water temperatures and flow discharge to estimate oxygen concentrations between Woodland and Milltown. These models make accurate predictions, but they are too complex to use operationally to make short term flow adjustments to improve oxygen concentration. Attempts have been made to use easily measured parameters, such as specific conductance and oxygen saturation, but if minimum discharges were maintained on a continuous basis instead of a mean daily basis, there is little likelihood of violating the oxygen objective. Hydrologic and hydraulic models could also be applied to the river to predict lake/ reservoir levels when certain flows are required for maintenance purposes, but at present there is no computer model used operationally.

WATER QUANTITY

Why were lake levels low in recent years?

During the last seventeen years, 1969-85, there have been a number of years (1971, 1974, 1975, 1978 and 1985) when normal precipitation was not available to sustain flows required by control regulation, and it was necessary to draw more on the storage reserve than usual. The years 1971 and 1985 were particularly dry years. The results in each case have been perceived low water levels and complaints from cottage owners, fishermen, recreation/tourism and fishing organizations, even though Georgia-Pacific has met the flow and water level regulations imposed by the I.J.C.

Figure 9 illustrates these low lake levels and the corresponding years of low precipitation.

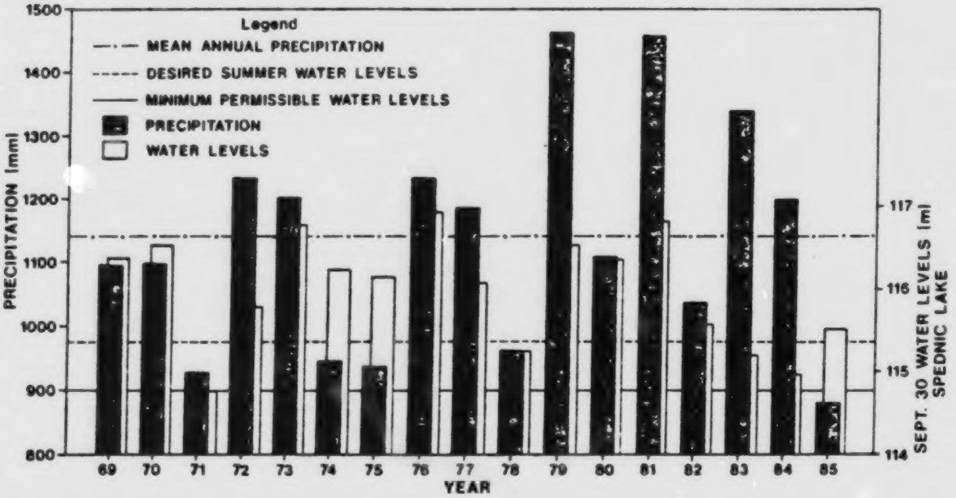


Figure 9 Mean Annual Precipitation and Spednic Lake Water Levels (Based on Records from Canterbury, New Brunswick - Vanceboro and Woodland, Maine)

How much flow discharge is required for fisheries?

Flow discharge requirements for fisheries is related to the need for fish passage and fish habitat protection which means sufficient flow discharge for passage, dilution of pulp mill effluent to maintain oxygen levels and sufficient water to cover nursery and rearing areas and to control rapid fluctuations in water level. The principal problem with flow discharge and fisheries is the need to maintain sufficient dissolved oxygen and pH water quality objectives. Fisheries and Oceans Canada has prepared a long term management plan for the diadromous fisheries of the St. Croix River, but this does not include flow requirements such as those recommended by Maine Department of Environmental Protection. One major improvement would be to require maintenance flow on an instantaneous basis rather than a mean daily basis. Flows can now be maintained to provide the required 24 hour mean but, in reality, large fluctuations could still occur on an instantaneous basis. The 1980 fish kill further illustrates this, as the required 21.2 m^3/s (750 cfs) mean daily discharge below Woodland was not violated on a 24 hour basis, but oxygen concentration went as low as 0.5 mg/l when flows did drop below the 21.2 m^3/s (750 cfs) for several hours.

What would flows be like if the river were not regulated?

The effects of regulation are clearly demonstrated by comparing natural and regulated outflows for the four major reservoirs in the basin. The extreme highs and lows are moderated to a significant degree. During extended periods of drought (in 1985) the flows are low under both "natural" and "regulated" conditions. However, even under extended periods of drought, regulated flows tend to be higher than those under natural conditions.

If the river were not regulated, the monthly distribution of the runoff would be more variable. Summer flows and water levels would be lower and the spring freshets higher and some lakes could virtually cease to exist by reverting back to a river run. During periods of low precipitation natural flows would generally be lower than regulated flows (Figure 10).

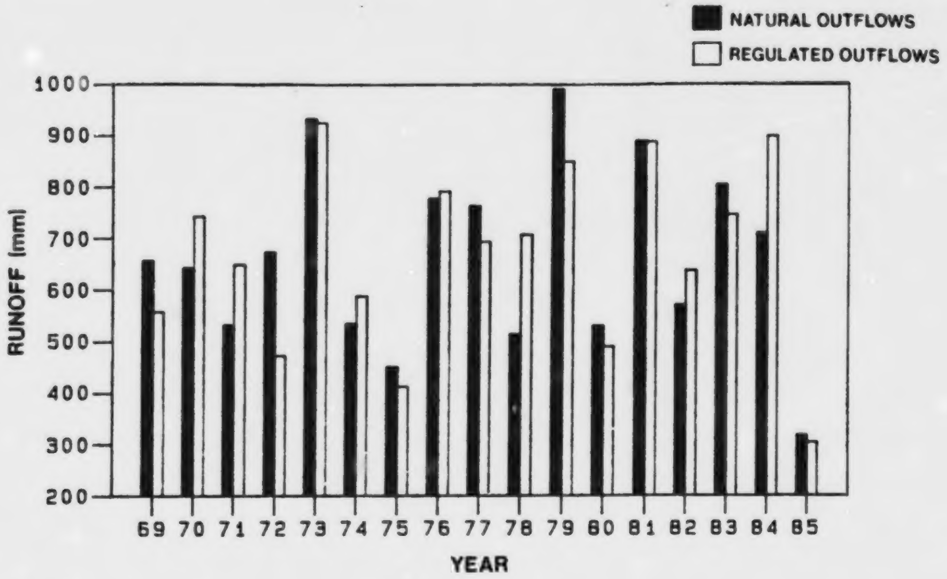


Figure 10 Annual Mean Runoff, Spednic Lake, Period 1969 to 1985

Could the rule curve be changed to satisfy water level requirements as well as providing downstream maintenance flows?

The current maintenance flow of the 21.2 m^3/s (750 cfs) required at Woodland is a large factor in reducing the existing, upstream storage and producing lake level drawdowns during periods of deficient rainfall. If increased downstream flows were required the drawdown problem on the upstream lakes, especially Spednic Lake would be aggravated. In periods of prolonged drought, such as the sixteen month period of July 1984 through October 1985, natural rainfall runoff, which provides lake inflows, becomes negligible and virtually all lake outflows come from storage. This is the reason why regulatable storage was established in the first place.

A very delicate and complicated balance exists in this basin. To satisfy all the concerned individuals may be next to impossible as the lake level requirements run counter to the downstream maintenance flow requirements. However, to assist in answering this question, more study and modelling of potential scenarios would be required to determine the feasibility of meeting both flow demands and demands to increase minimum lake levels. At present there is no computer model for the basin available to evaluate the effects of a change in the rule curve.

What are the needs of flow for recreational use of the river by the general public?

Specific flow requirements in terms of discharge are difficult to quantify for recreational use, but it is clear that most recreation is water related.

Angling is the principal recreational activity in the basin, and a conservative estimate of its value is $1,300,000 (Cdn.) per year, not including local residents fishing trips. Canoeing/ Kayaking is a growing sport (over 6,000 canoeists used the river in 1982) as the St. Croix River has some of the best canoeing routes in Eastern North America and provides a full range of river conditions. Georgia-Pacific indicates that canoeists would prefer 12.7 m^3/s (450 cfs) or more be released from Vanceboro Dam to provide good conditions which is more than double the required I.J.C. minimum discharge of 5.66 m^3/s (200 cfs). With the increased emphasis on recreational use of the river, the potential of conflict with industrial uses could increase. Verbal communications with canoeists indicate displeasure with the aesthetic quality of the river below Woodland due to high colour and the presence of foam in the river.

Cottage use in the upper lakes has led to conflicts due to complaints about water levels, especially on Spednic Lake as cottage owners claim that the minimum required levels are set too low.

Other recreational activities include camping, RV use, cross country skiing, hunting and boating. To further define these needs additional detailed study is required.

Are there economic benefits to be gained by changes in flow regulation? By whom?

When we discuss "change" in flow regulation, it has been generally recommended that this means an "increase" in flows required below Woodland, which could result in lower lake levels as more water may be required from storage to meet these demands.

The issue of lake levels is mainly centred on Spednic Lake where concerns have been raised by lakefront property owners over the large fluctuation in water levels. These concerns have included: (i) lake access for boating and hazardous boat operations due to the exposure of boulders and rocks; (ii) low water table resulting in dry wells and freezing of water lines; (iii) fishing and fish spawning areas; (iv) shoreline erosion; (v) aesthetics; and (vi) loss of business to commercial camp operations and outfitters.

Obviously all of this has a negative economic benefit in the Spednic Lake area. However, during low flow periods, increased flows below Spednic Lake would be an aid to run-of-the-river activities such as canoeing, angling and aesthetic considerations. Increased flows, if high enough, would be routed through several hydroelectric power plants and would result in more hydroelectric power production by Georgia-Pacific.

If more run-of-the-river flow were available, it would also supply more water to N. B. Power for the Milltown hydroelectric power station. More water could improve fish habitat and provide better passage conditions for anadromous fish and the expected improvement in fish production could be of economic benefit.

Further study would be required to quantify actual benefits to downstream users versus the disadvantages to lakefront land owners and outfitters, in particular, on Spednic Lake.

What is the relationship between groundwater levels, well yields and lake levels in the system?

The cottage owners around Spednic Lake have experienced low water levels and dry wells. Regulation of the St. Croix River system has been cited as the possible source of these problems, particularly during the summers of 1971 and 1985. However, the climate and geology of the St. Croix River Basin at Spednic Lake likely accounts for the low water levels in dug wells rather than river regulation. Shallow dug wells, normally less than 6 metres (20 ft.) deep, are more often affected during droughts than deeper drilled wells having larger storage capacities. This problem is common throughout all of New Brunswick and Maine.

However, water table wells, particularly shallow dug wells, will often respond to river/lake stage changes if the soil in which they are located is permeable. This is due to the movement of surface water into and out of stream banks during rises and declines in river or lake stages. Clearly, this issue would require further study.

CONFLICTING USES

Who are the major users in the Basin?
What are their interests?
How are the user needs interrelated and what are the conflicts?

The major land and water user in the Basin has been Georgia-Pacific Corporation and it is expected that this will continue as forestry and forest products manufacturing is the principal economic activity in the Basin. Georgia-Pacific not only uses water for production purposes, but also generates hydroelectric power for their own operations. N.B. Power at Milltown also generates hydroelectric power using available run of the river flows. For example, in 1985, Georgia-Pacific generated about 77% of the total hydroelectric power with N.B. Power generating the balance.

In terms of land use, agriculture is a distant second to forestry, but agricultural activities utilize little water and exert little impact upon the water resource.

Fisheries and recreational pursuits are highly dependent upon the water resource and are in competition with, and at times in conflict with, the need to provide downstream maintenance flows, and at the same time maintain lake levels desired by lake users. This, in essence, is the major water management problem in the basin: HOW TO PROVIDE SUFFICIENT MAINTENANCE FLOWS FOR POLLUTION ABATEMENT AND OTHER FISHERY AND RECREATION DEMANDS VERSUS THE NEED TO PROVIDE STORAGE IN THE FORM OF LAKES CONTROLLED BY DAMS FOR HYDROELECTRIC POWER PRODUCTION, AND TO PROVIDE ADEQUATE LAKE LEVELS FOR RECREATIONAL PURPOSES.

Consumptive uses of the water, both in terms of surface water and groundwater, can mainly be attributed to municipal and industrial water uses. Over half of the basin population is served by public water systems and most of these utilize groundwater as their source. The communities served by public systems located along the main river ceased using surface water early in this century when water quality deteriorated with the growth of the pulp and paper industry. St. Andrews has a surface water source in Chamcook Lake, but watershed protection is of concern with about 70 cottages located in the watershed. Generally, the sources of supply have been adequate in quality and quantity for most communities, but McAdam has had petroleum contamination of one well that is now only used for fire protection. McAdam also has about 70% of its population served by dug or drilled wells, and there have been chronic problems with quality due to contamination by sewage and petroleum. Even with improvements, approximately 1,100 people still use private wells. A report on the St. Croix Waterway Recreation Area has also recommended establishment of infrastructure to support the expanded recreational use of the area. All of these improvements exert further demands on the existing water supply and sewage treatment facilities.

The major industrial user, Georgia Pacific, withdraws water from the river and has its own treatment plant to improve the quality of river water for process purposes. Georgia-Pacific currently discharges 67% of its licensed effluent discharge. Georgia-Pacific water withdrawal is estimated to be approximately equal to its discharge of processed water so that its water withdrawal is estimated to be about 100,500 m^3 (27 million U.S. gallons) per day. This demand also represents about 10 times the demand of all of the public water systems combined. It should be noted that dilution of effluent has been effective in meeting the water quality objectives established for fish, at least as measured well downstream at Milltown.

How is co-ordination of uses achieved, given the interjurisdictional nature of the Basin?

There are a host of International, Federal (both Canadian and U.S.), State and Provincial and Municipal Acts, Statutes, Regulations and By-laws which affect activities in the St. Croix River Basin. However, the International Joint Commission, the U.S. Environmental Protection Agency, and Fisheries and Oceans Canada are the major regulatory agencies in the Basin at the International level. The Maine Department of Environmental Protection and the New Brunswick Department of Municipal Affairs and Environment also have a major interest in water quality in the basin. The I.J.C. has established flow and water level regulations for most of the dams on the main stem of the St. Croix River to maintain lake levels, minimum flows for fisheries purposes and, in the case of the river below Woodland, to provide sufficient water to meet water quality objectives for dissolved oxygen and pH. Actual river regulation is left in the hands of Georgia-Pacific Corporation, the owner of the dams, to provide the required flows and water levels. The I.J.C. monitors the required flows, water levels and water quality objectives and reports annually on deviations. The Maine Department of Environmental Protection and the New Brunswick Department of Municipal Affairs and Environment both monitor water quality as well and occasionally recommend improvements in operating procedures to further enhance water quality. Georgia-Pacific also operates other dams within the basin using operating procedures designed to provide suitable fish habitat, fish passage and other waterfowl habitat.

RECREATIONAL DEVELOPMENT

What scenarios are being developed for recreational development, and what is their impact?

Greater emphasis is now being placed on recreational development as an alternative to the general decline in economic activity over the last three decades. Recreation and tourism are perceived to be a means of improving the economy on both sides of the border in the St. Croix River Basin.

The proposed designation of the St. Croix as an Heritage River and the formation of the St. Croix Waterway Recreation Area is expected to add encouragement to the development of recreational facilities and an increase in activities along the river. This will require additional camping, outfitter and other tourism facilities. The intent is to establish low-key development.

The impacts of recreational development are both socio-economic and environmental. These include the effects of restrictions or changes in land use, increased visitations to an area, increased competition for the fish resource, increased employment or sources of income, increases in expenditures by visitors, effects on changes to soil, flora, fauna, water quality and aesthetics, and pressure on archeological sites.

The principal economic benefit expected from recreational development is the increase in total regional income and employment opportunities. Proposed development is expected to be at a low scale with limited capital investment, and therefore environmental impact is predicted to be minimal in the short to medium term. The major problem will be the control of litter or other human generated wastes at campsites and along the roadside. Monitoring and management options can be utilized to mitigate the environmental impacts.

Is the watershed capable of sustaining development without impact?

The concept of carrying capacity in the recreation/tourism sector must be kept in mind when evaluating the adverse effects or impacts due to tourism development. There is obviously a limit to any resource to absorb an ever-increasing number of visitors or development beyond which the quality of the experience is adversely affected. This carrying capacity is physically limited by available physical spaces and accommodation; by environmental factors such as water quality, and potential destruction of flora and fauna, etc., and also by the public attitude toward the quality of the experience. The St. Croix Waterway Recreation Area studies have concluded that the designated area should have a physical capacity of less than 650 persons per day, provided that they are distributed throughout the area. There is no quantitative information on the effects on the quality of the experience, or on adverse environmental effects.

SUMMARY

The main water resources issue is the apparently conflicting user demand to maintain or even raise minimum lake levels in Spednic Lake versus providing storage for hydroelectric production, forest products processing and downstream maintenance flows for: pollution abatement, the fishery resource and recreational requirements.

At present, it is difficult to quantify the effects of raising lake levels as desired by property owners, and still be capable of providing downstream maintenance flows. The results obtained by the comparison of natural versus regulated outflows clearly indicates that regulation is beneficial by reducing extremes of runoff. In other words, peak flood flows are reduced and minimum flows are kept at a higher level.

In order to more accurately estimate the possibility of maintaining higher lake levels or increasing maintenance flows, hydrologic and hydraulic modelling studies would be required to simulate the behaviour of the St. Croix River in terms of reservoir operations. Various scenarios could be envisioned for study purposes based upon the operation of the two main portions of the watershed controlled by Georgia-Pacific above Grand Falls instead of utilizing only lakes along the international boundary.

At the present time, Georgia Pacific has been carrying out the control of lake levels and the provision of maintenance flows almost without exception within the I.J.C. requirements. However, the Grand Falls Dam at Kellyland does not have any I.J.C. requirement for minimum flow, but Georgia-Pacific does provide flows that result from their turbine operations. The concern is that flow demands are being met at the expense of lake levels in the regulated lakes, but it must be recognized that there is a finite volume of water available for storage and release downstream for minimum maintenance flows. Also, the Maine Department of Environmental Protection has recommended more precise flow control by requiring instantaneous discharge instead of mean daily flow discharge. They further recommended that flows be increased during the dry summer period. These measures would prevent the type of fish kill that occurred in 1980 due to low dissolved oxygen, even though no technical violation of flow requirement occurred. However, there is a question of whether there is sufficient available water to raise flows during the summer, at least in years of below average rainfall.

Land use patterns in particular in the forestry/pulp and paper industries, are not expected to change to any large degree. However, recreation/tourism activities are expected to increase as a result of promotion of the St. Croix River as a Heritage River and as the St. Croix River Waterway Recreation Area. This growing importance will probably lead to increased conflict between historic uses such as industrial and hydro-electric power generation and recreational uses. Therefore, the demand for greater control of lake level elevations will be in contention with the need to provide minimum maintenance flow discharges downstream.

Other activities of concern in the watershed include: a potential nuclear waste storage site in Maine, the possibility of the formation of dioxins in the river from pulp mill effluent, construction of a recovery furnace/boiler installation and the clean-up of PCBs at site along a Meddybemps lake which occasionally drains into the St. Croix River.

AFTERWORD

This report has presented an overview of the Technical Report results with an interpretation of the data and illustrating the importance of integrating data so that an appreciation of the potential conflict can be gained.

The impact of land use and socio-economic activities must be taken into account when considering water quality objectives and the hydrological capability of the basin to provide the necessary water to optimize water management.

The Technical Report produced by the St. Croix River Basin Pilot Project is a detailed and comprehensive document. The foregoing overview is designed only to present an interpretive overview of the issues raised by the Technical Report, and to place them in an understandable context. The original document, obviously, covers these issues in much greater depth. Readers wishing a fuller treatment of the subject matter discussed above may obtain a copy of the Technical Report and/or related information at the address below.

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ST. CROIX RIVER

Integrated Data Interpretation

TECHNICAL REPORT

1987

Prepared by:

St. Croix River Pilot Project Team
Inland Waters Directorate
Conservation & Protection
Atlantic Region
Dartmouth, Nova Scotia

December 1987

SECTION ONE

INTRODUCTION

1.0 INTRODUCTION

A Pilot Project on Integrated Data Interpretation was initiated by the Inland Waters Directorate (I.W.D.) in October, 1985 in response to a Regional Management Committee decision launching a joint water quality and quantity data interpretation project for FY 1986-87.

The project commenced in April 1986 with the development of a conceptual work plan. The Project Team was assembled and work was underway during the preparation of the Terms of Reference which were finalized and approved in September 1986.

The project objectives were:

(1) to complete a pilot I.W.D., Atlantic Region, data integration interpretation project by March 31, 1987, meeting the information needs of agencies and individuals in the management of the St. Croix River; and

(2) to enhance public awareness of the issues related to the St. Croix River basin, and to present information on the current river operations and the limitations imposed by its hydrologic regime;

This project is related to the need to provide leadership and direction to promote management of the water resource on a sustainable basis. The purpose of this report is to provide an integrated assessment of activities in the St. Croix River Basin for use by resource managers. This report will be followed by a publication presenting an overview of the St. Croix River Basin to enhance public awareness of the issues.

The scope of work includes the collection and interpretation of data for surface water and groundwater; water quality; land use; socio-economic issues; and other areas pertinent to the St. Croix River Basin. Other information will include a profile on river users, designation of the St. Croix Waterway Recreation Area, nomination of the St. Croix as a Heritage River, and plans in progress related to tourism, recreation, and fisheries enhancement projects.

The project team (See Figure 1.1, Project Team Organizational Chart) consisted of personnel from the three I.W.D. Branches, including: Water Planning & Management Branch (WP&MB), Water Resources Branch (WRB), Water Quality Branch (WQB). Initial assistance was provided by the Communications Directorate, Conservation and Protection.

Project Team Organizational Chart

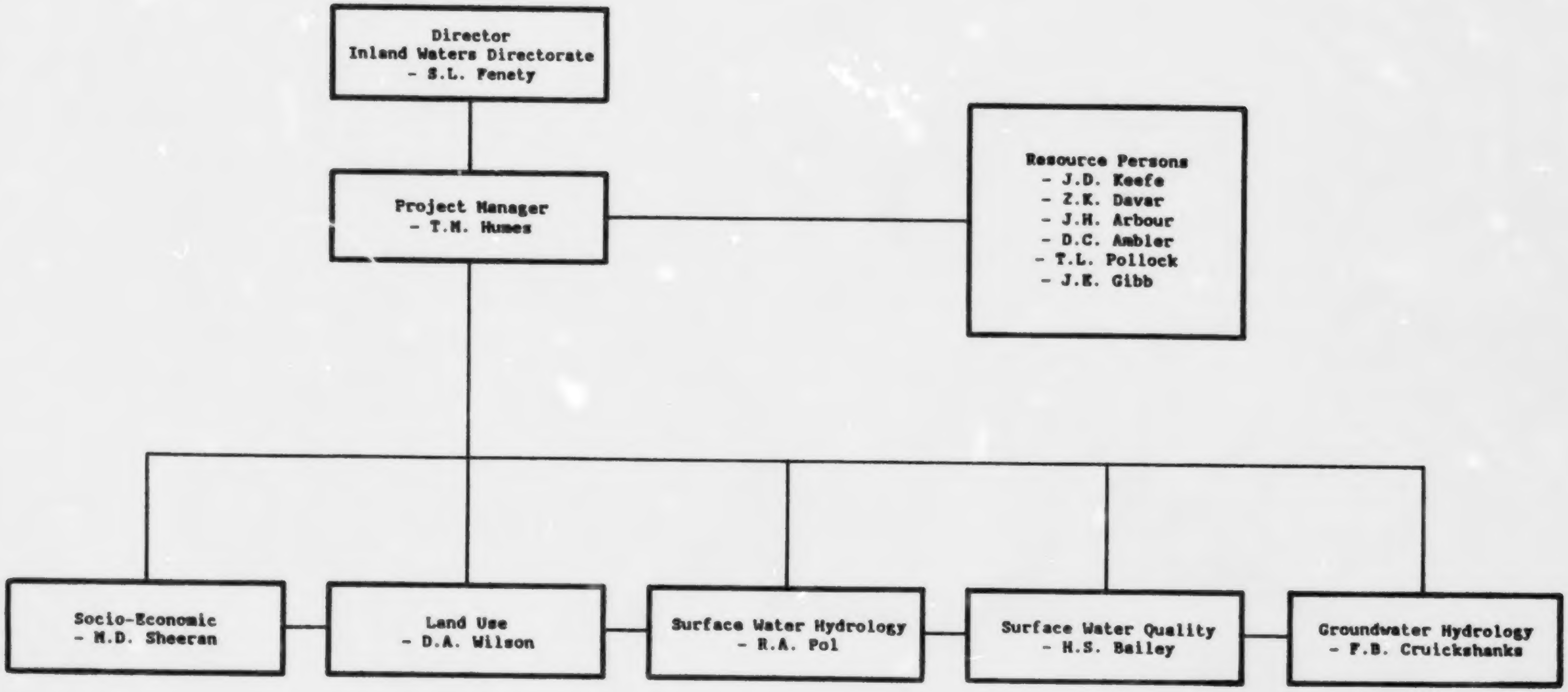

Director
Inland Waters Directorate
- S.L. Fenety
Project Manager
- T.M. Humes
Resource Persons
- J.D. Keefe
- Z.K. Davar
- J.H. Arbour
- D.C. Ambler
- T.L. Pollock
- J.E. Gibb
Socio-Economic
- M.D. Sheeran
Land Use
- D.A. Wilson
Surface Water Hydrology
- R.A. Pol
Surface Water Quality
- H.S. Bailey
Groundwater Hydrology
- F.B. Cruickshanks

Figure 1.1

SECTION TWO

St. CROIX RIVER BASIN STUDY AREA

2.0 ST. CROIX RIVER BASIN STUDY AREA

2.1 LOCATION AND CLIMATE

The St. Croix River Basin, 4230 km^2 in area, straddles the Canada-United States border between southwestern New Brunswick and southeastern Maine. The basin is bounded on the north by the Saint John River Basin, on the west by the Penobscot River Basin, and on the south and east by coastal streams. Figure 2.1, "St. Croix River Basin Pilot Project Study Area", highlights the drainage basin.

The St. Croix River Basin has a continental climate, characterized by cold winters and warm summers. The prevailing westerly winds and the cyclonic storms that cross the continent from west to east bring most of the precipitation, except for occasional heavily laden coastal storms.

The mean annual precipitation for the basin is 1140 mm (Figure 2.2) with fairly uniform distribution throughout the year. The annual snowfall over the watershed varies from about 200 cm in the southern portion of the basin to nearly 285 cm at inland locations.

The mean annual temperature of the basin is 5.3°C with recorded daily temperatures ranging from 37.8°C to minus 40.6°C.

2.2 PHYSIOGRAPHY AND DRAINAGE

The New Brunswick and New England physiographic provinces, which lie within the St. Croix Basin, form part of the Appalachian Highlands as shown on Figure 2.3. In Maine, the basin is generally divided into two divisions - the Seaboard Lowland and the New England Upland, while in New Brunswick, the basin is largely occupied by the St. Croix Highlands and a small portion of the Miramichi Highlands.

The lowlands in the basin lie below an elevation of 152.4 m (500 feet), with low hills rising over 100 metres above the lakes and swampy plains. A few hilltops and some monadnocks reach elevations of 304.8 m (1000 feet) to over 365.8 m (1,200 fet). Musquash Mountain, at an elevation of 377.3 m (1,238 feet), is the highest point in the basin.

The basin has the shape of an irregular "Y" with two principal chains of lakes, the Northern Group along the International boundary, and a Western Group in the State of Maine, both of which join at Kellyland along the main stem of the river. The river then flows southeasterly along the international boundary, becoming tidewater at St. Stephen and empties into Passamaquoddy Bay.

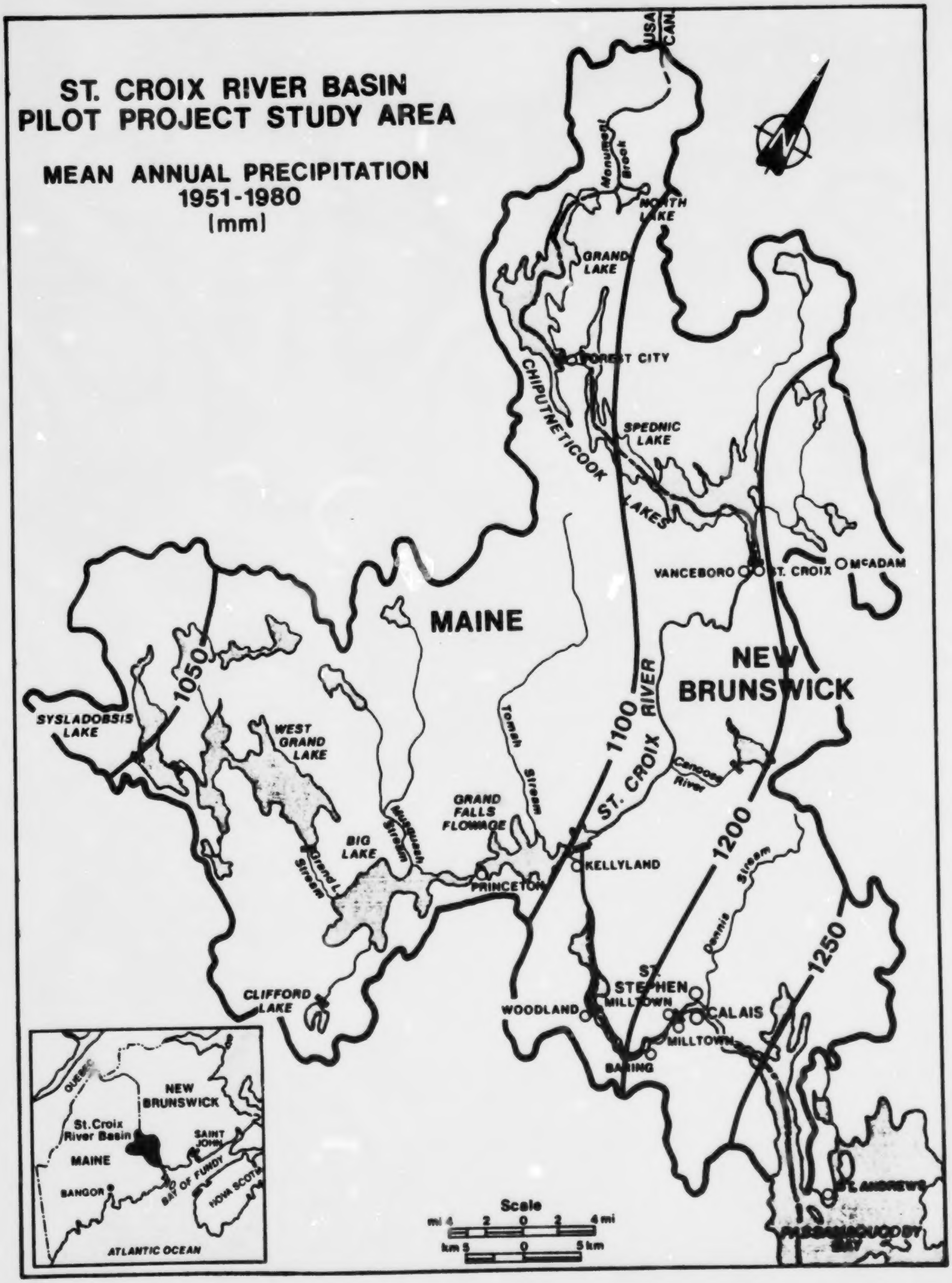

ST. CROIX RIVER BASIN
PILOT PROJECT STUDY AREA
MEAN ANNUAL PRECIPITATION
1951-1980
(mm)
USA
CAN
Monument Brook
NORTH LAKE
GRAND LAKE
FOREST CITY
CHIPUTNETICOOK LAKES
SPEDNIC LAKE
VANCEBORO
ST. CROIX
McADAM
MAINE
NEW BRUNSWICK
1050
1100
1200
1250
SYSLADOBSIS LAKE
WEST GRAND LAKE
Tomah Stream
ST. CROIX RIVER
Canoose River
GRAND FALLS FLOWAGE
BIG LAKE
Musquash Stream
Grand L. Stream
PRINCETON
KELLYLAND
Dennis Stream
ST. STEPHEN
MILLTOWN
WOODLAND
CALAIS
MILLTOWN
BARING
CLIFFORD LAKE
ST. ANDREWS
PASSAMAQUODDY BAY
Scale
mi 4 2 0 2 4 mi
km 5 0 5 km
QUEBEC
NEW BRUNSWICK
St. Croix River Basin
MAINE
SAINT JOHN
BANGOR
BAY OF FUNDY
NOVA SCOTIA
ATLANTIC OCEAN

Figure 2.2

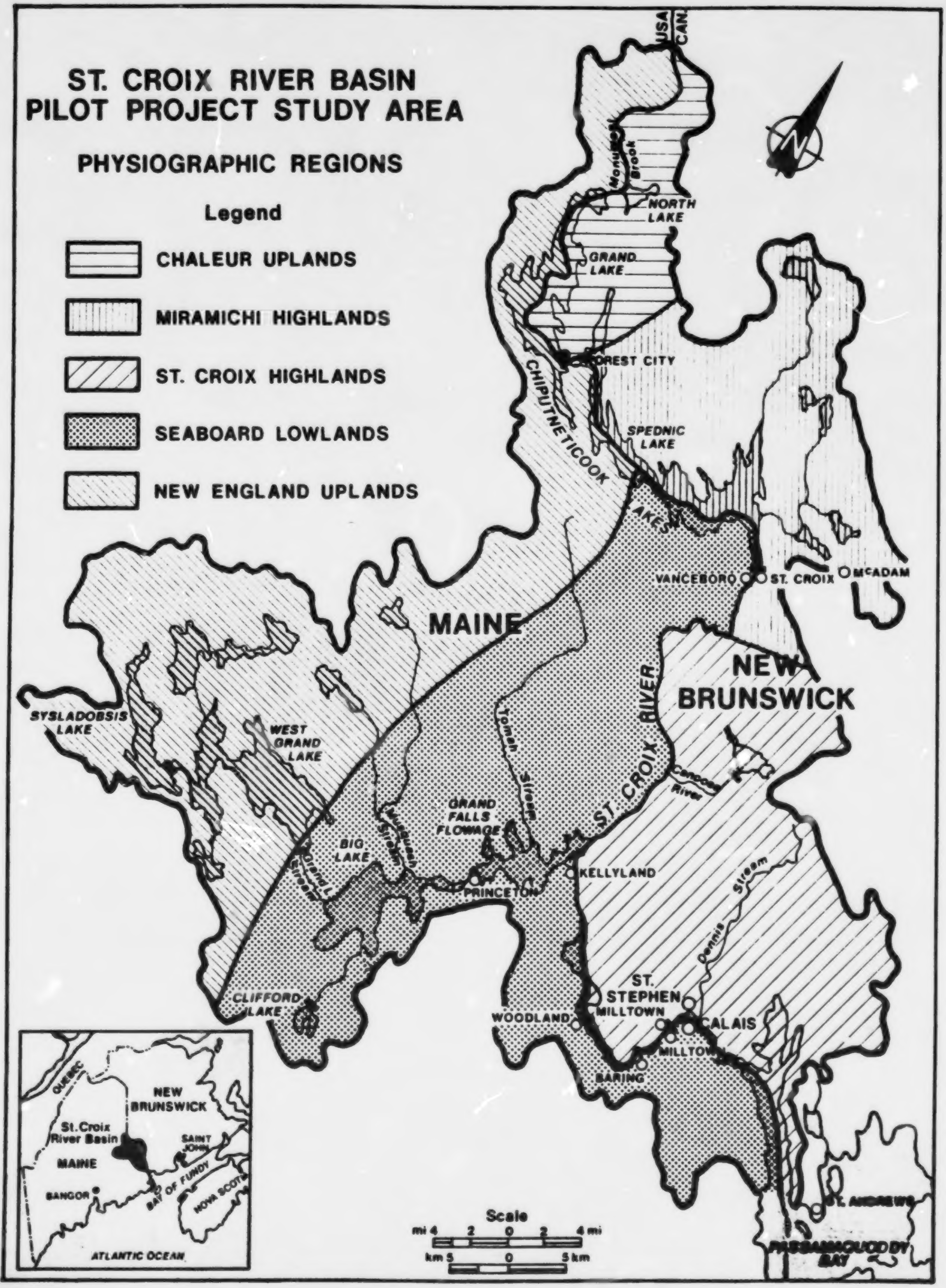

ST. CROIX RIVER BASIN
PILOT PROJECT STUDY AREA
PHYSIOGRAPHIC REGIONS
Legend
CHALEUR UPLANDS
MIRAMICHI HIGHLANDS
ST. CROIX HIGHLANDS
SEABOARD LOWLANDS
NEW ENGLAND UPLANDS
USA
CAN
Monument Brook
NORTH LAKE
GRAND LAKE
FOREST CITY
CHIPUTNETICOOK
SPEDNIC LAKE
LAKES
VANCEBORO
ST. CROIX
McADAM
MAINE
NEW BRUNSWICK
SYSLADOBSIS LAKE
WEST GRAND LAKE
Tomah Stream
ST. CROIX RIVER
Canoose River
GRAND FALLS FLOWAGE
BIG LAKE
Grand Lake Stream
Stream
PRINCETON
KELLYLAND
Dennis Stream
CLIFFORD LAKE
WOODLAND
ST. STEPHEN
MILLTOWN
CALAIS
MILLTOWN
BARING
ST. ANDREWS
PASSAMAQUODDY BAY
Scale
mi 4 2 0 2 4 mi
km 5 0 5 km
QUEBEC
NEW BRUNSWICK
St. Croix River Basin
MAINE
SAINT JOHN
BANGOR
BAY OF FUNDY
NOVA SCOTIA
ATLANTIC OCEAN

Figure 2.3

The headwaters of the St. Croix River begin with Monument Brook which flows into North Lake, then into Grand Lake (known as East Grand Lake in the U.S.) near Fosterville, through Mud Lake below Forest City and into Spednic Lake (known as Spednik Lake in the U.S.), forming the Chiputneticook Lakes System. For purposes of this report, the mainstem of the river is considered to be the river reach along the international boundary.

The river leaves Spednic Lake at Vanceboro, following an irregular meandering course in a southerly direction for about 87 km (54 miles) to tidewater at Calais/St. Stephen. Along this course, the Grand Falls Flowage enters the river at Kellyland through the Grand Falls Dam and then proceeds into Woodland Lake which is released from the Woodland Dam and Georgia-Pacific plant to continue its journey past Baring to Milltown and finally joining with tidal water of the estuary. The estuary extends from approximately the International Bridge at Calais/St. Stephen to empty into Passamaquoddy Bay which is southeast of Robbinston, Maine/ St. Andrews, New Brunswick.

"In the 124 km (77 miles) of its length between the outlet of Grand Lake and mean highwater at Calais, the river falls a total of 129.2 m (424 feet). Nine feet of this fall are between Grand and Mud Lakes and 12.5 m (41 feet) are between Mud and Spednic Lakes. The remaining 114 m (374 feet) of fall are in the St. Croix River below Spednic Lake" (Source: New England-New York Inter-Agency Committee, 1955; metric units added).

In the estuary, the mean range of tide at St. Andrews is 6.0 m (19.6 feet), and at St. Stephen, 6.2 m (20.5 feet). The large tide range at St. Andrews is 8.3 m (27.2 feet). There was no large tide range available for St. Stephen in the 1987 tide tables, but obviously the large tide range at St. Stephen will be higher than the mean range and can be expected to be in the order of 8.5 to 8.8 m (28 - 29 ft.). This range is relatively high and could exert a considerable backwater effect on the natural river flows.

On the west side of the watershed in Maine, there are several lakes which feed into the Grand Falls Flowage, which enters the main river at Kellyland, and these include: Sysladobsis Lake, Junior Lake, West Grand Lake, and Big Lake, as well as others. The tributaries in New Brunswick drain a much smaller area and generally join the main river at separate locations, rather than being a network which ultimately flows into the main river at one point as it predominantly is for the Maine portion of the watershed. These streams are tributaries to the Chiputneticook Lakes system and also include such streams as: Canoose Rier, Mohannas Stream and the Dennis Stream.

It should also be noted that there are adjoining watersheds in Maine to the south that also probably contribute flow to the St. Croix River, especially at high water levels in the adjacent lakes. For example, Meddybemps Lake, through on-site observation, flows to the St. Croix River through Stoney Brook and also flows south to the Dennys River. Available topographic mapping also indicates there are other streams whose flow could cross the accepted drainage basin boundary. This would appear to occur in the headwaters of the Machias River but, due to the nature of these low inter-basin areas, it could require extensive study to establish an acceptable drainage basin delineation. For the purposes of this study, the U.S.G.S. drainage basin delineation has been accepted and has been confirmed with the U.S.G.S.

2.3 BEDROCK GEOLOGY

Bedrock of the St. Croix River basin largely consists of Paleozoic era rocks and younger intrusions ranging in age from Precambrian to Upper Devonian (Figure 2.4) and closely folded beds of Ordovician and Silurian rocks which dip steeply with their fold axes trending northeast-southwest. The large masses of igneous and metamorphic rocks which occupy the basin are mainly comprised of granites, quartzites, argillites, and local schists and gneisses. Metamorphic rocks underlie the upper northern and western fringes of the basin. Paleozoic intrusives, mostly granites, surround the Chiputneticook Lakes from Monument Brook, extending southeasterly to the outflow above Vanceboro. Granitic rocks surround the Sysladobsis and also the Grand Lake system within the western limit of the basin. Metamorphic sediments occupy the south and east central portions of the basin. The St. Croix River and most of the tributaries cut across the trend of these metamorphic rocks until encountering granitic terrain between Woodland and Calais, where the main stem forms a sharp bending loop. Red sandstone and conglomerate of Upper Devonian to early Mississipian age occupy a small area just outside the Basin near St. Andrews. A small amount of these

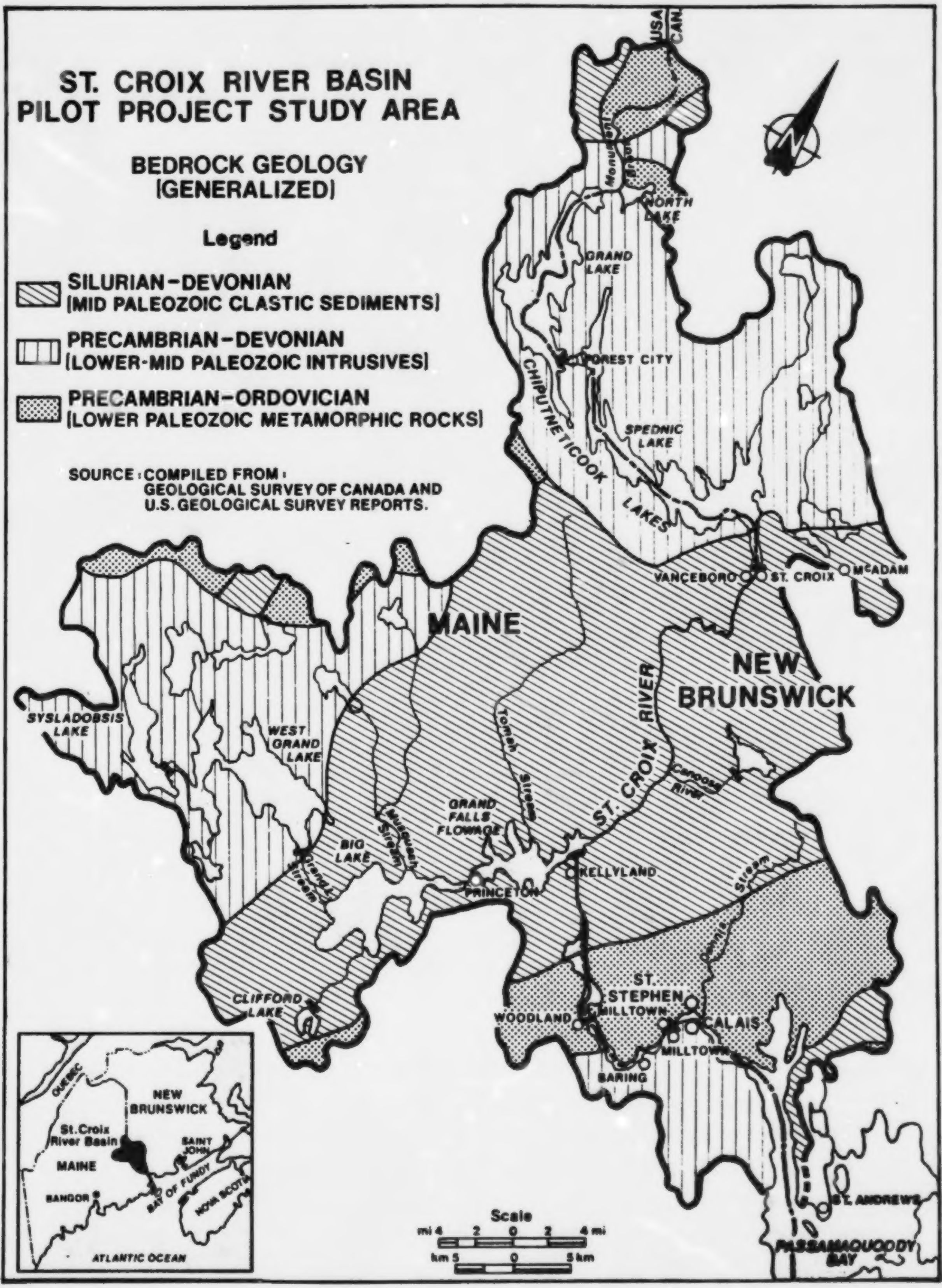

ST. CROIX RIVER BASIN
PILOT PROJECT STUDY AREA
BEDROCK GEOLOGY
(GENERALIZED)
Legend
▨ SILURIAN-DEVONIAN (MID PALEOZOIC CLASTIC SEDIMENTS)
▥ PRECAMBRIAN-DEVONIAN (LOWER-MID PALEOZOIC INTRUSIVES)
▩ PRECAMBRIAN-ORDOVICIAN (LOWER PALEOZOIC METAMORPHIC ROCKS)
SOURCE: COMPILED FROM: GEOLOGICAL SURVEY OF CANADA AND U.S. GEOLOGICAL SURVEY REPORTS.
USA
CAN
Monument Brook
NORTH LAKE
GRAND LAKE
FOREST CITY
CHIPUTNETICOOK LAKES
SPEDNIC LAKE
VANCEBORO
ST. CROIX
McADAM
MAINE
NEW BRUNSWICK
ST. CROIX RIVER
Tomah Stream
Canoose River
SYSLADOBSIS LAKE
WEST GRAND LAKE
GRAND FALLS FLOWAGE
BIG LAKE
Musquash Stream
Grand Lake Stream
PRINCETON
KELLYLAND
Stream
Dennis Stream
ST. STEPHEN
MILLTOWN
WOODLAND
CALAIS
MILLTOWN
BARING
CLIFFORD LAKE
ST. ANDREWS
PASSAMAQUODDY BAY
Scale
mi 4 2 0 2 4 mi
km 5 0 5 km
QUEBEC
NEW BRUNSWICK
St. Croix River Basin
SAINT JOHN
MAINE
BANGOR
BAY OF FUNDY
NOVA SCOTIA
ATLANTIC OCEAN

Figure 2.4

sediments occupy an area on the U.S. side of the border, too small to show in Figure 2.4, and is considered to be the youngest consolidated formation in the basin.

2.4 SURFICIAL GEOLOGY

The overburden throughout the St. Croix basin was largely deposited during the most recent, Wisconsinian, glacial stage (Figure 2.5). Typical unconcolidated surficial materials include morainal and glaciofluvial deposits, interlayered marine silt and clay and peat deposits.

Morainal deposits of varying thickness cover much of the St. Croix basin. These deposits consist primarily of till, but in many places are comprised of a complex of ablation till, lodgement till, glaciofluvial deposits, colluvium and weathered bedrock (Rampton and Paradis, 1981a). Morainal deposits (tills) are generally exposed only at the surface of hills because extensive areas where these materials were deposited have themselves been buried by later glacial outwash and marine sediments. The textures and colours of tills are closely related to the underlying bedrock and the bedrock immediately upglacier from the site of deposition. Igneous rocks, volcanics and metasediments produce till with significant stone contents, generally exceeding 35% (Rampton, et al, 1984). Bouldery tills are a common phenomenon in areas of granitic bedrock (Gadd, 1973). Surficial covers are generally thin over hills and deeper in bedrock valleys. Deposits of till in bedrock valleys can reach depths of more than 100 metres (Maloney and Cowing, 1985). Most tills, however, are a few metres or less in thickness.

Glaciofluvial deposits often overlie the till in valleys and broad lowland areas. Glaciofluvial deposits are those primarily deposited over or against ice (ice-contact deposits) or those deposited in a proglacial position (outwash).

Ice-contact stratified deposits have been described by (Brinsmead, 1977, p. 14) as characteristically comprising varying amounts of silt and clay. Ice-dropped boulders are common in this material. Stratification of ice-contact deposits is commonly contorted and faulted. Abrupt changes in grain size and degree of sorting are characteristic of such deposits as well. Gauthier (1983) and Rampton and Paradis (1981a) noted that ice-contact deposits commonly contain diamicton beds or ablation till, which is poorly sorted, but partially washed of fines. Large

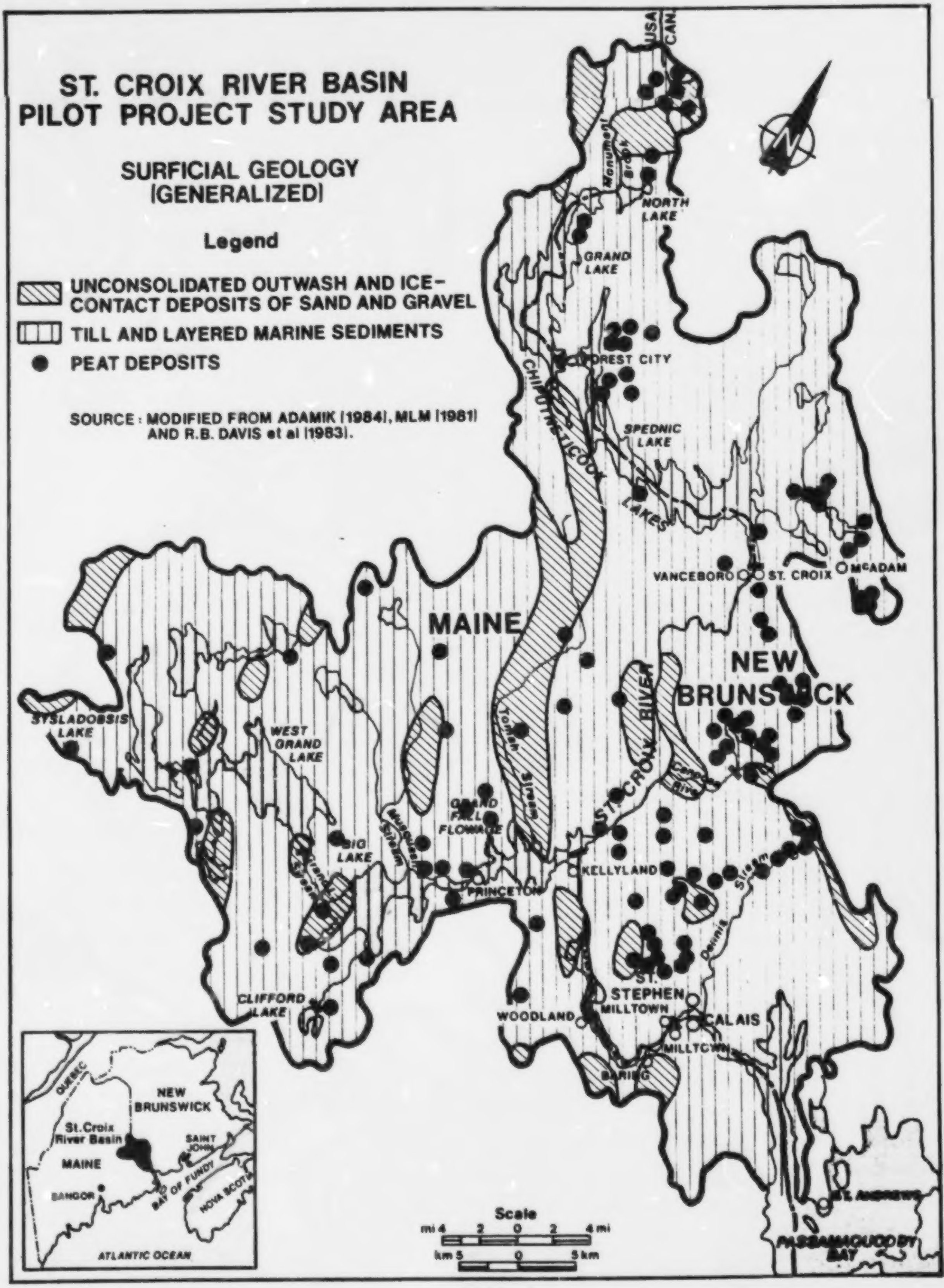

ST. CROIX RIVER BASIN
PILOT PROJECT STUDY AREA
SURFICIAL GEOLOGY
[GENERALIZED]
Legend
▨ UNCONSOLIDATED OUTWASH AND ICE-CONTACT DEPOSITS OF SAND AND GRAVEL
▥ TILL AND LAYERED MARINE SEDIMENTS
● PEAT DEPOSITS
SOURCE: MODIFIED FROM ADAMIK [1984], MLM [1981] AND R.B. DAVIS et al [1983].
USA
CAN
Monument Brook
NORTH LAKE
GRAND LAKE
FOREST CITY
SPEDNIC LAKE
CHIPUTNETICOOK LAKES
VANCEBORO
ST. CROIX
McADAM
MAINE
NEW BRUNSWICK
SYSLADOBSIS LAKE
WEST GRAND LAKE
Tomah Stream
ST. CROIX RIVER
Canoose River
GRAND FALLS FLOWAGE
BIG LAKE
Grand Lake Stream
Musquash Stream
PRINCETON
KELLYLAND
Stream
Dennis Stream
ST. STEPHEN
MILLTOWN
CALAIS
MILLTOWN
WOODLAND
BARING
CLIFFORD LAKE
ST. ANDREWS
PASSAMAQUODDY BAY
QUEBEC
NEW BRUNSWICK
St. Croix River Basin
SAINT JOHN
MAINE
BANGOR
BAY OF FUNDY
NOVA SCOTIA
ATLANTIC OCEAN
Scale
mi 4 2 0 2 4 mi
km 5 0 5 km

Figure 2.5

boulders have been noted as a common constituent of ice-contact deposits throughout New Brunswick (Gadd, 1973; Melvin, 1966). This common association led Gauthier (1982) to group many ice-contact deposits with ablation till in a unit designated as ridged and hummocky disintegration moraine.

Ice-contact deposits usually form eskers, kames, kame terraces and deltas, and kame and kettle complexes. A prominent esker has developed along the Tomah Stream in the central area of the basin. Several eskers are situated on the west side of the main river near Spednic Lake, and eskers also occur south of Grand Lake in the Valley of the Little Musquash Stream, and along the shore of Grand Falls Flowage, east of Princeton, Maine.

Brinsmead (1977, p. 15) has described outwash in general as being "typically well sorted and fairly well stratified gravel and sandy gravel. The content of fine particles is usually low in outwash deposits, as the meltwater from which the coarse material is deposited tends to carry the fines farther downstream"; he qualifies deltaic deposits as follows: "The base of a typical section comprises fine to silty fine sand with silt interbeds, grading upwards through medium, sands and pebbly sand into medium-pebble to small cobble gravel near the surface. Stratification is much more regular and laterally continuous than that of outwash, which is more likely to exhibit cut-and-fill structures and truncated bedding" (Brinsmead, 1977, p. 16).

Outwash and ice-contact deposits fill numerous preglacial valleys, and appear in plain view as elongated and discontinuous exposures (Figure 2.5).

Isostatic adjustments of land levels and eustatic changes in sea level caused portions of the St. Croix River basin to be covered by marine, brackish or lacustrine waters during and following deglaciation. Gravel, sand, silt, and clay of varying thickness were deposited in these water bodies. Marine clays often interlay outwash deposits in some lowlands.

Isolated deposits of gravel, sand, silt and clay at levels well above the accepted levels of marine submergence were deposited in glacially dammed lakes, or lakes owing their existence to post glacial isostatic depression and tilting of the terrain (Rampton et al, 1984).

Maloney and Cowing (1985) illustrated a typical surficial sequence which can be found in the preglacial valleys of the St. Croix basin (Figure 2.6). The block diagram shows the bedrock covered by a layer of till. Thick ice-contact sand and gravel deposits overlie the till along the valley and walls, and through the centre of the valley. Marine silt and clay overlie the till and the lower part of the ice-contact deposits. Outwash sand and gravel deposits overlie the marine silt and clay and the upper part of the ice-contact deposits.

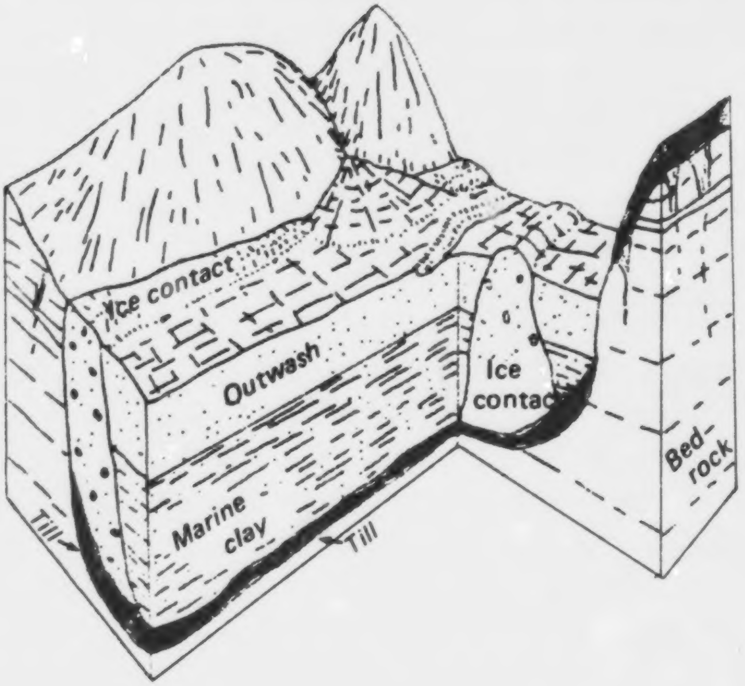


Figure 2.6 Typical Stratigraphic Sequence

The St. Croix River basin also contains numerous deposits of organic material and peat which occupy extensive swampy areas throughout the basins.

2.5 LAND USE

'Land Use' refers to the man's activities as reflected in the physical appearance and condition of landscapes. Subsequently, land use is often described in terms of human activity that is taking place and the corresponding land cover.

Land use information for the St. Croix Watershed has been drawn from a wide variety of sources. In both Canada and the United States, there have been programs carried out to compile data on broad land use descriptions. In Canada, this was done under the Canada Land Inventory (C.L.I.) and in the U.S. under he U.S. Geological Survey Land Use/Land Cover map series. The C.L.I. and U.S.G.S. prepared maps at a scale of 1:250,000 based on original mapping at a scale of 1:50,000. This information was originally collected from air photos and local information, but since it was collected in and about the late 1960s, it is somewhat out of date now, and dramatic changes could have occurred in high growth areas. Other land use information is also available through census data, municipal planners and through the analysis of remote sensing imagery, as well as through aerial reconnaissance.

2.5.1 General Description of Land Use in the St. Croix River Basin

Land use in the St. Croix River Basin is predominantly forestry related (Figure 2.7). The majority of the area (approximately 75%) of the basin consists of forest cover. Forestry activities can include both the production of trees and the active harvesting or stockpiling of cut trees. The proportion of forest land use is similar on both the Canadian and American sides of the basin (Table 2.1). This is not surprising given the very similar nature of the landscapes and the historical use patterns on both sides of the basin.

Agricultural land use, including rangeland, is the next highest activity in the basin, occupying approximately 5% of the basin, with the majority being on the Canadian side. Much of this land falls in the improved cropland/pasture category. Such categories would include the use of land for raising dairyanimals and other livestock. The extent of horticultural or specialized uses is quite limited. The majority of the

TABLE 2.1
LAND USE IN THE ST. CROIX RIVER WATERSHED
(Area in Hectares)

Land Use	Maine	New Brunswick	Total
Agricultural Land	6 015	12 260	18 275
Rangeland	145	2 763	2 908
Forest Land	187 545	128 985	316 530
Urban	1 585	784	2 369
Wetlands	24 007	4 931	28 938
Unproductive Land	1 470	5 479	6 949
Fresh Water			47 031
TOTAL			423 000

agricultural land would have grass cover of some sort. Blueberry production is a land use that is expanding in the basin.

Somewhat less than 1% of the watershed land use is urban associated. The remaining land, such as wetlands, unproductive and freshwater, exhibits no visible activity (about 20% of the total). The overall distribution of land use is illustrated in Figure 2.8.

The land use/land cover of the Canadian side of the St. Croix River basin reflects the capability of the landscape to support various land use practices. The Canada Land Inventory gives a good indication of the production of agricultural and forest products. Although the capability information is not available for the American side, it is reasonable to extrapolate the characteristics from the New Brunswick side because of the similarities in climate, soils and physiography. Figure 2.9 illustrates agricultural capability and Figure 2.10 illustrates forest capability.

The Canadian side of the watershed is devoid of any Class 1 or 2 capability of soil for agriculture. These are the only classes that do not involve significant limitations. Class 3 agricultural land occupies approximately 30% of the basin.

The most predominant of these physical limitations is stoniness and poor soil structure. The structure problems usually relate to root growth. In some cases, the stoniness limitations are accompanied by thin soils. These limiting conditions are found on almost all of the land improved for agriculture, however, they are not severe enough to prohibit the development of agriculture. In the remainder of the watershed, the soil conditions are not conducive to agriculture. There the problems include steep topography, thin soils and severe stoniness. This remaining area provides the basis for the widespread forest sector which is found in the watershed. Over 80% of the watershed is in tree production and a great portion of that is held in licences by Georgia-Pacific. The lands are predominantly Class 4 for forest production (Figure 2.10). As with the agricultural soils, there are a number of factors which limit the productivity of the soils. These are restrictions on the rooting zone by bedrock, low fertility and excess soil moisture. These limitations reflect the thin soils over bedrock that are characteristic of many of the forested areas (Canada Land Inventory, 1970).

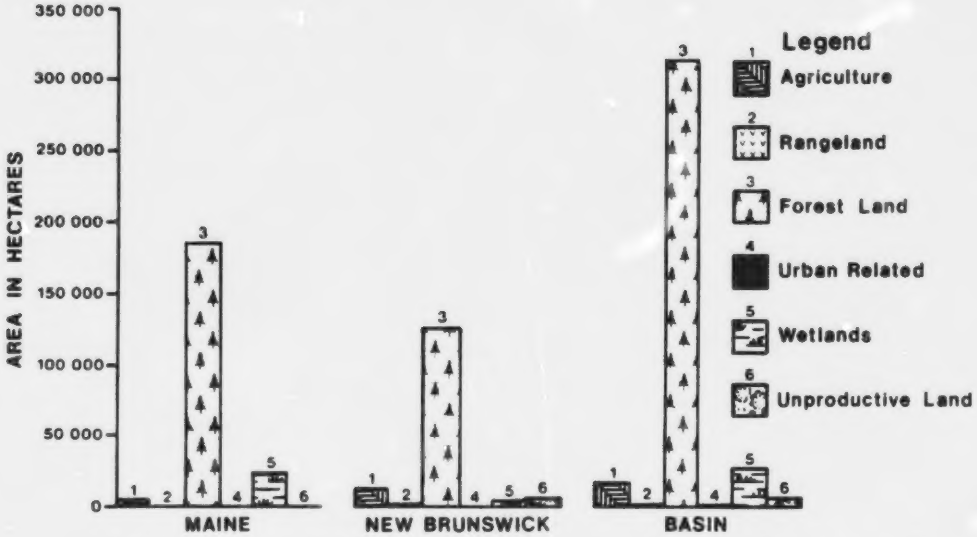


Figure 2.8 Land Use in the St. Croix River Basin

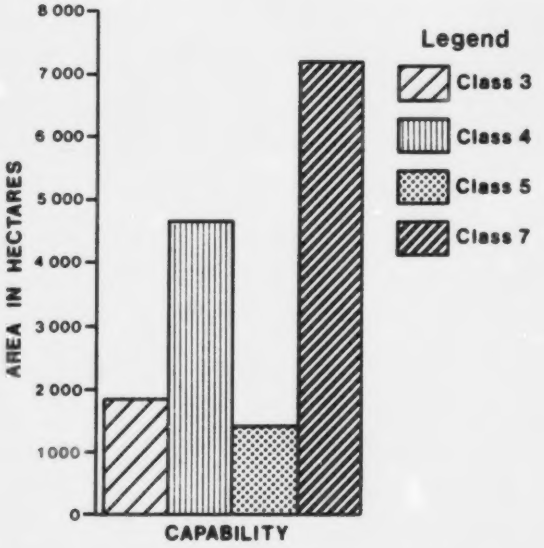


Figure 2.9 Agricultural Capability on the Canadian Side of the Basin

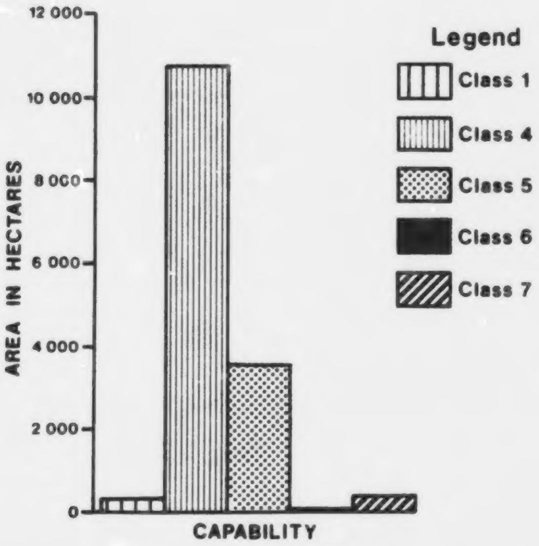


Figure 2.10 Forest Capability on the Canadian Side of the Basin

2.5.2 Remote Sensing for Land Use

A light aircraft was used as a rapid and economical means of obtaining a reconnaissance of the watershed, most of which is inaccessible to conventional ground survey methods. The Cessna high-wing aircraft facilitated unobstructed photography (35 mm) to document the observations noted. These photographs and observations were also helpful in interpreting Landsat imagery.

As a means of updating the existing land use information assembled, a new source was acquired and visually analysed. Four Landsat satellite Thematic Mapper scenes covering the St. Croix Watershed were obtained from the Canadian Centre for Remote Sensing (C.C.R.S.). This imagery provided 30 metres ground resolution in six of the seven spectral bands sensed, and it represents the latest generation of Landsat sensor technology; both in spatial and spectral resolving capabilities. The imaging dates included 11 and 18 August, 1985. Spectral bands 2, 3 and 4, those recommended for land use analysis, were processed in positive colour film transparency format (scale 1:1 million) suitable for magnification and information transfer on the Environment Canada's Procom-2 transfer device. These images were processed at C.C.R.S. as 'bulk geometric corrected' and when projected onto the study area map, the match - image to map - was precise enough to make data transfer an effortless operation.

The interpretation of basin wide land use information from the four images provided a uniform overview as well as an update on land related data for both the U.S. and Canadian side of the basin. Trends in changing land activity in the basin were obtained. The forestry and agricultural practices proved more difficult to delineate than these same land use classes located outside of the basin. On an identical image, the forest cutover and the agricultural crop patterns are more regular in size and shape to the north of the St. Croix watershed.

Land use practices within the basin differ considerably from those taking place in areas adjacent to the basin. There is little evidence of the large shaped forest clear-cuts found to the north of the basin. Instead, there are scattered, irregular-shaped outlines of forest harvesting that vary considerably in age.

A similar non-regular pattern is evident in the scattered agricultural fields within the watershed, when compared to the agricultural zone to the north. It proved difficult to interpret the transitional areas where farmland is abandoned, grassland that is reverting to shrub cover, or where old forest cutovers are regenerating to a dense new tree cover. The land use class 'unproductive land' (see Figure 2.7) could not be distinguished on the satellite imagery. Nor could the forest agricultural activities be ascribed quantitative values that would be possible in more homogeneous areas outside the basin, even though both areas fall within the same Landsat scene.

Within the regular pattern and the relatively long period of activity in the region, the presence of logging roads was used to indicate the location of forest operations. The highest density of these roads exists in the south-central part of the watershed below Big Lake and continues outside of the basin. Other forest road concentrations appear southeast of Fosterville, both sides of Bolton Brook, and smaller scattered sites throughout the study area.

Another means of inferring the type and location of future or past forestry operations is to delineate the type of forest cover. It is possible to separate softwood, hardwood and mixed wood on the imagery. For example, if hardwood continues to be the main raw material required for the pulp and paper process, the Skiff Lake area is likely to attract harvesting activity as it was found to consist mainly of deciduous forest cover. On the other hand, this area would not attract harvesting for the stud mill and waferboard plant as they require softwoods only.

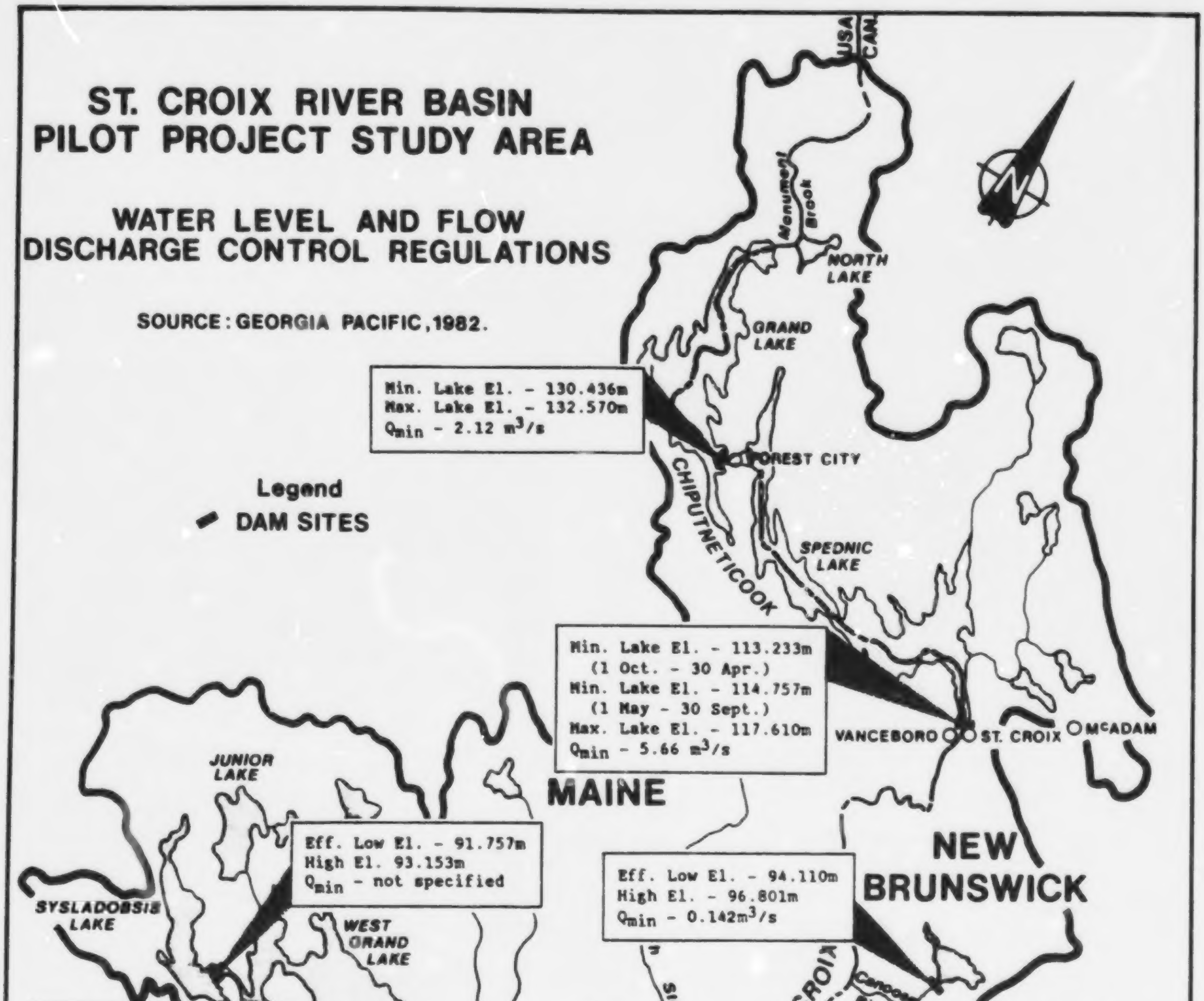
A direct projection of the 1985 Landsat images to the 1970-75 land use map for the agricultural class indicates a notable decrease in the area under agricultural production on the imagery. The scattered nature of the activity made the quantification of the land area involved, at best, a rough estimate without employing digital analysis techniques.

The visual analysis of the Landsat imagery did target a major land clearing effort at Butterfield Landing. As well, the exposed littoral zone on Grand and Pocumcus Lakes is an indication of lower water levels than normal which the surface water hydrology section verified 1985 as a low precipitatic year. A similar case was not evident for other lakes in the watershed. In contrast, the Landsat image gives an example of a major increase in flooded area when compared to the topographic map on Upper Canoose Flowage and the Canoose Flowage.

2.6 FLOW AND WATER LEVEL REGULATION

The St. Croix River is extensively regulated through a series of dams on the main river and on all of the major lakes. These lakes provide storage for power generation and natural flow augmentation to provide minimum flow discharges as required by various regulatory orders. These dams are operated by Georgia-Pacific Corporation (G-P) primarily for their own needs and also to meet the flow and minimum/maximum lake levels as required by control regulations. In general, over the last several years, Georgia-Pacific has been successful in meeting these orders as a result of: several years of operating experience, and data availability on snow cover, snow water equivalent, precipitation, runoff, water levels and discharge. Georgia-Pacific also utilizes detailed Watershed Control Procedures (February, 1982) related to the operation of the dams used to meet these requirements. The International Joint Commission's Board of Control established a rule curve for the operation of the St. Croix River Reservoir in 1965. Later, a regulation study was carried out on Spednic Lake and, in 1978, the I.J.C. confirmed that the existing regulations would remain in force. It should be noted that the original regulations were specified in English units and it would appear that conversion to metric values, as published by Georgia-Pacific in their 1982 St. Croix Watershed Control Procedures does not match those published by the I.J.C., even though they are close. It should also be noted that I.J.C. orders only apply to Spednic Lake and East Grand Lake (now Grand Lake) where flows are regulated along the main river which is the international boundary. The U.S.E.P.A. requires flow regulation below Woodland for pollution abatement purposes. Georgia-Pacific also operates other dams on both sides of the border which are subject to other control regulations. Figure 2.11 is a schematic illustrating the relationships between reservoirs, dams, minimum flow and minimum/maximum water level requirements. The reader is referred to Section 4.2 for a more thorough description of these requirements.

These minimum flow discharge requirements and water level regulations are vehicles for water management of the St. Croix River Basin, but complaints have been registered about the range of fluctuation allowed, in particular on Spednic Lake, where cottage owners and other recreational activities are affected.



ST. CROIX RIVER BASIN
PILOT PROJECT STUDY AREA

WATER LEVEL AND FLOW
DISCHARGE CONTROL REGULATIONS

SOURCE: GEORGIA PACIFIC, 1982.

Legend
DAM SITES

Min. Lake El. - 130.436m
Max. Lake El. - 132.570m
Q_{min} - 2.12 m^3/s

Min. Lake El. - 113.233m
(1 Oct. - 30 Apr.)
Min. Lake El. - 114.757m
(1 May - 30 Sept.)
Max. Lake El. - 117.610m
Q_{min} - 5.66 m^3/s

Eff. Low El. - 91.757m
High El. 93.153m
Q_{min} - not specified

Eff. Low El. - 94.110m
High El. - 96.801m
Q_{min} - 0.142m^3/s

Min. Eff. El. - 89.614m
Max. Lake El. - 91.876m
Q_{min} - 2.83 m^3/s

Eff. Low El. - 60.582m
High El. - 62.106 m
Q_{min} - 24.1 m^3/s

Eff. Low El. - 67.949m
High El. - 70.336m
Q_{min} - 0.142m^3/s

Not specified

Eff. Low El. - 42.468m
High El. - 43.077m
Q_{min} - 21.2 m^3/s^*

USA
CAN
N
Monument Brook
NORTH LAKE
GRAND LAKE
FOREST CITY
CHIPUTNETICOOK
SPEDNIC LAKE
VANCEBORO
ST. CROIX
McADAM
JUNIOR LAKE
MAINE
NEW BRUNSWICK
SYSLADOBSIS LAKE
WEST GRAND LAKE
St. Croix
Canoose River
Stream
Grand L. Stream
BIG LAKE
Musquash Stream
GRAND FALLS FLOWAGE
PRINCETON
KELLYLAND
Dennis St.
CLIFFORD LAKE
ST. STEPHEN
MILLTOWN
CALAIS
WOODLAND
MILLTOWN
BARING
ST. ANDREWS
PASSAMAQUODDY BAY
QUEBEC
NEW BRUNSWICK
St. Croix River Basin
MAINE
SAINT JOHN
BAY OF FUNDY
NOVA SCOTIA
BANGOR
ATLANTIC OCEAN
Scale
mi 4 2 0 2 4 mi
km 5 0 5 km

Figure 2.11

2.7 WATER QUALITY

Water quality has been improving over the last several years to the extent that anadromous fish are being reintroduced to the system. Some estuary areas continue to be plagued by fecal coliform contamination resulting in shellfish area closures or the need for depuration processes.

In general, water quality in the St. Croix River is a reflection of the surficial geology and the influence of human activities in the basin. Due to the relatively rapid runoff of precipitation and snow melt water, the water in the upper reaches of the River is low in dissolved solids and is coloured by drainage from bogs in that region. In the lower reaches of the river below Woodland, water quality is characterized by the effluent from the pulp and paper mill. In addition, the estuary receives domestic and municipal sewage and the resulting fecal coliform counts prevent the consumption of shellfish. Fresh river water in the main stream lower reaches is also not suitable for domestic consumption due to pulp and paper effluent discharge.

Water quality objectives have been established for the St. Croix River as follows: a dissolved oxygen concentration of 5.0 mg/l with 60% saturation and for pH from 6.0 to 8.5. Generally over the past several years, these objectives have been met except for a notable exception in 1980 when a fish kill occurred as a result of reduced river flows. Even though the mean daily discharge did not drop below the required maintenance flow, it is evident that low discharges, which occur on an instantaneous basis, can cause D.O. to drop below objective levels.

This improvement in river water quality has resulted from changes in mill processes and improvements in effluent treatment, but river quality below Woodland is still not suitable for some recreational activities.

2.8 JURISDICTIONAL CONSTRAINTS

Socio-economic activities in the St. Croix River Basin are regulated by Canadian and United States federal, provincial/state, and municipal statutes. Those statutes which pertain directly to water management in the Basin are described below.

2.8.1 INTERNATIONAL LAWS AND REGULATIONS

Administering Agency	Act/Statute	Description
1. Department of External Affairs	(a) International Boundary Waters Treaty	Establishes rules and principles which govern the use and development of the water resources common to Canada and the United States, and establishes the International Joint Commission (IJC) regulatory power over the use, obstruction, or diversion of boundary waters as they relate to potential changes in water level or flows.
2. Department of Energy, Mines and Resources	(a) International Bounary Commission	Establishes a Commission overseeing all work on the international boundary.

2.8.2 FEDERAL LAWS/REGULATIONS

A. CANADA

Administering Agency	Act/Statute	Description
1. Environment Canada	Canada Water Act	Designed to promote management of national water resources through the researching, planning, and implementation of programs involved with conservation, development and the utilization of these resources.
2. Fisheries and Oceans	The Fisheries Act	Manages the fish resources of Canada (one section, pertaining to the release of deleterious substances into water bodies, is administered by Environment Canada). Other sections of the Act have provisions for fishway construction/control, and management of fish habitat.
3. Transport Canada	Navigable Waters Protection Act	Concerned with water flows and levels as they pertain to navigational use of a water body. All works on any navigable water body will be subject to approval of the Minister and this Act.
4. Environment Canada	International River Improvements Act	Prohibits the construction, operation and maintenance of river improvements such as dams, obstruction, canals, reservoirs or other works which would have a deleterious effect on boundary waters. A valid license is required under this Act.

2.8.2 FEDERAL LAWS/REGULATIONS (cont'd)

B. UNITED STATES

Administering Agency	Act/Statute	Description
1. Environmental Protection Agency	Federal Water Pollution Control Act	Intended to eliminate discharge of pollutants into navigable waters by 1985 and to limit the amount of pollution from future development along these waters.
2. U.S. Army Corps of Engineers	The Rivers and Harbours Act	Authorizes the U.S. Army Corps of Engineers to review all proposed alterations and obstructions to navigable waters in the U.S.
3. Federal Energy Regulatory Commission	Federal Power Act	Makes the Commission responsible for the issuing of permits and licenses for non-federal hydro-power projects, and regulating rates and other aspects of such projects. Also requires the development of recreational facilities for the general public at licensed hydroelectric projects where a need is demonstrated.
4. Federal Fish and Wildlife Service	The Fish and Wildlife Act-Fish and Wildlife Coordination Act	Ensures the consultation of any Federal Agency with the U.S. Fish and Wildlife Service, the head of the Maine Department of Inland Fisheries and Wildlife, and the National Maine Fisheries Service before major undertakings designed to control or modify any body of water are done. All agencies involved with the protection of fish and wildlife resources are responsible for examining the impact of any licensing or construction activity, and safeguarding the fish and wildlife resources within water resource development programs.

2.8.3 PROVINCIAL/STATE LAWS/REGULATIONS

A. New Brunswick

Administering Agency	Act/Statute	Description
1. Community Improvement Corporation	Community Improvement Corporation Act	Under Order-in-Council, delineates the St. Croix Waterway Recreation Area which has been designated as an area for the chairmanship of the Interdepartmental Management Committee which will co-ordinate the management of the St. Croix Waterway Recreation Area.
2. Department of Municipal Affairs and Environment	Clean Environment Act	Concerned with the regulation of the release of wastes into the environment and control of any watercourse alteration or control structure.
3. Department of Natural Resources	Crown Lands and Forests Act	Enacted for the development, utilization protection, and integrated management of the resources of crown lands (includes management of fish and wildlife habitat and watershed protection).
4. Department of Transportation	Highway Act	Controls the use of resource access, prohibits/regulates litter disposal and protects watershed lands.

B. Maine

Administering Agency	Act/Statute	Description
1. Department of Environmental Protection	a) Coastal Wetlands Law	Regulates development activities such that they will not unreasonably interfere with existing recreational and navigational uses, water quality and flow standards, wildlife and fisheries, and soil erosion standards.
	b) Great Ponds Act	Intended to protect the scenic, recreational, cultural, historical and environmental value of any national inland waterbody in excess of 10 acres (3.9 ha) which is owned by two or more persons. Also regulates dredging, construction and land attractions.

B. Maine (cont'd)

Administering Agency	Act/Statute	Description
	c) Litter Control Act	Prohibits the discharge or spillage of sewage, refuse, or other waste materials into water courses or on their banks.
	d) Milldams and Canals Act	Allows the erection of watermills or dams on individual's property for purposes of working that land. The diversion of a stream's natural channel is also permitted for purposes of powering mill or machinery.
	e) Site Location Act	Controls the location of large subdivisions or development to minimize adverse environmental impact, e.g. water quality, erosion, historic sites, unusual natural areas, scenic character, wildlife and fisheries.
	f) Protection of Waters Act	Designates four standards (A,B,C,D) for the classifying of surface waters and determining the types of usage and degree of contamination permitted.
	g) Solid Waste Disposal Act	Prohibits the solid waste contamination of inland and tidal waters.
2. Department of Inland Fisheries and Wildlife	a) Endangered Species Act	Conserves, protects, maintains and enhances the number of the various species of fish or wildlife which are facing extinction.
	b) Fishways and Dams	Owners of dams and similar obstructions may be required to construct a fishway in those waters containing migrating fish such as salmon, shad and alewives.
	c) Rivers, Streams and Alteration Act	Requires that a permit be issued for dredging, filling, or erecting a causeway, bridge, marina, wharf, dock or other permanent structure which would have an impact on water bodies.

2.8.3 PROVINCIAL/STATE LAWS/REGULATIONS (cont'd)

B. Maine (cont'd)

Administering Agency	Act/Statute	Description
1. Maine State Planning Office	a) Mandatory State Shoreland Zoning and Subdivision Control	Administered at the local level, the Act establishes that land within 250 feet (approx. 80 m) of normal high water mark of any pond, river or salt water body, be subjected to zoning or subdivision controls.
	b) An Act to Promote the Wise Use and Management of Maine's Outstanding River Resources	Identifies certain rivers that are to be protected by existing municipal shoreland zoning ordinances. These ordinances are being reviewed for their adequacy. The Act establishes special protection for the St. Croix because it is an international boundary - it prohibits further development in certain sections of the basin with some exceptions.
4. Land Use Regulation Commissions (LURC) (Washington County Regional Planning Commission)	Land Use Regulation Commission	Plans and regulates use of lands in the plantations, unorganized townships, and coastal islands of the State. The Washington County Regional Land Use Commission is responsible for land regulation in the Maine section of the St. Croix.

2.8.4 Local Laws and Regulations

Administering Agency	Act/Statute	Description
1. Municipalities	a) Zoning By-laws	
	b) Building by-laws	
Note:	Municipalities include the Towns of St. Stephen and Calais, Village of McAdam, etc.	

2.8.3 PROVINCIAL/STATE LAWS/REGULATIONS (cont'd)

B. Maine (cont'd)

Administering Agency	Act/Statute	Description
4. Maine Municipal Planning Board	a) Mandatory Shoreland Zoning Law	Administered in accordance with State Minimum Guidelines.
	b) Regulation of Maine Manufactured Housing Law	As above
	c) Subdivision Law	Subdivision will be approved if it will not result in undue water or air pollution, soil erosion, impact on other aspects of the St. Croix River.

Source: Adapted from Community Improvement Corporation and Tourism, Recreation and Heritage Policy Planning Section, 1986.

SECTION THREE
SOCIO - ECONOMIC PROFILE

3.0 SOCIO-ECONOMIC PROFILE

3.1 INTRODUCTION

This section presents a profile of the St. Croix River Basin from an historical perspective describing economic activities that are taking place in the Basin such as: pulp and paper processing, power generation, recreation, tourism and food processing. Land use activities related to forestry, agriculture and others are further discussed.

Observations on the socio-economic conditions in the river basin are based on Statistics Canada (StatsCan) census information for the years 1971, 1976, and 1981, and a report compiled in late 1986 by the Quebec Labrador Foundation - Atlantic Centre for the Environment (QLF-ACE) under a contract with Environment Canada, Inland Waters Directorate, Atlantic Region, literature reviews and personal communications.

3.1.1 HISTORICAL PERSPECTIVE

The St. Croix River Basin was first inhabited 10,000 years ago by Paleo Indians, and then successively by various Indian cultures of the Archaic, Susquahanna, and Ceramic time periods, Europeans (from 1604 onwards), American citizens seeking political refuge in the Canadian section of the Basin (Loyalists during the American Revolution and political refugees during the American Civil War), and other more recent non-indigenous groups (DPA Consulting Ltd., 1984). The St. Croix River was recognized as a political boundary after the Treaty of Paris of 1783, and continues to the present day to be part of the Canada-U.S. border.

In the mid to late 1800s and early 1900s, exploitation of the extensive timber tracts in the area and construction of railways prompted an economic boom in the region. While there has been a subsequent economic decline, forest industries continue to be the mainstay of the local economy. The St. Croix River Basin has, in the past few decades, also attracted increased numbers of tourists and recreational/sports enthusiasts, prompting the development of an associated service industry.

Settlement patterns reflect the importance the St. Croix River has played in the development of the area economy. The most populous towns - Calais, St. Stephen, St. Andrews, and Baileyville (Woodland), are located on the mainstem of the river. The St. Croix River, used in the past as a means of transporting supplies and raw materials, is now used for power generation and recreational activities.

3.1.2 CURRENT POPULATION

The St. Croix River Basin has a population of approximately 20,500 people, over 70% of which is concentrated in the southeastern section of the Basin in and around the commercial centres of St. Stephen, New Brunswick/Calais, Maine. Municipalities with populations of 1,000 people and over are listed in Table 3.1 for 1980.

The Basin population has declined since the turn of the century (Figure 3.1) at an average rate of -0.2% per year. From 1970 to 1980

TABLE 3.1

INCORPORATED MUNICIPALITIES WITH POPULATIONS OF 1,000+ PEOPLE

Incorporated Municipality	1980 Population
Baileyville (Woodland)	2,100
Calais	4,000
McAdam	1,600
Princeton	1,000
St. Andrews	1,800
St. Stephen	5,100

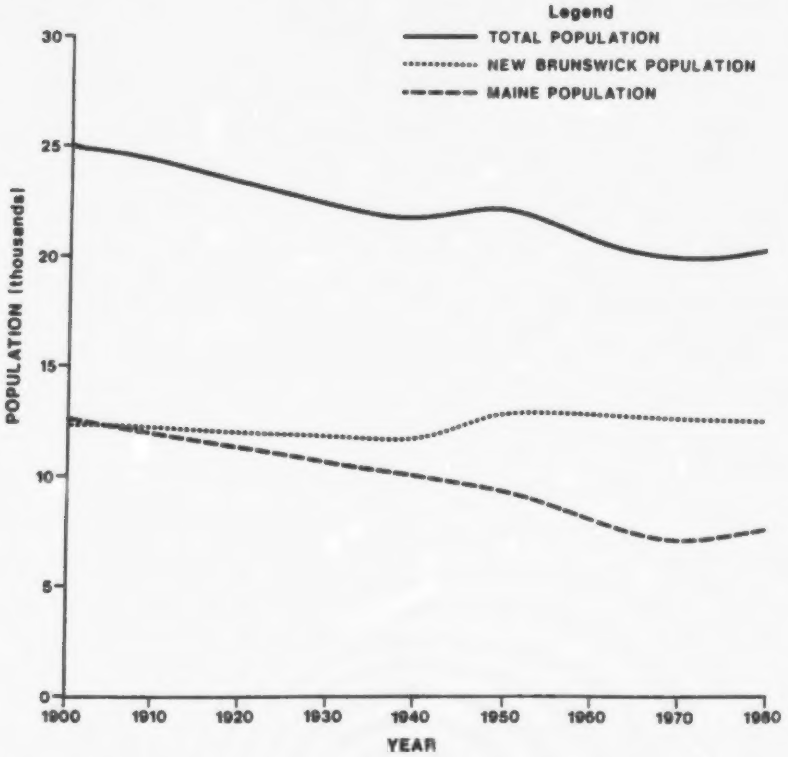


Figure 3.1 St. Croix River Basin Population, 1900-1980

there was, however, a slight increase in population which has been attributed to an influx of people attracted by the life style offered by the area. Some of these people subsequently left (L. Greer, Washington County Planning Commissioner, personal communication, 1986). It is interesting to note that, in the period 1900 - 1980, the Basin had a net increase of 250 people in New Brunswick, while Maine had a net loss of 4,800 (Table 3.2).

TABLE 3.2

MAINE - NEW BRUNSWICK POPULATIONS IN THE ST. CROIX RIVER BASIN

Year	Maine	New Brunswick	Total
1900	12,560	12,440	25,000
1940	10,000	11,800	21,800
1950	9,400	13,000	22,400
1970	7,240	12,750	19,990
1980	7,747	12,690	20,400

The 1980 labour force was approximately 40% of the population, with an unemployment rate of approximately 12%. However, with recent plant closures (1980 to present), there are areas in the Basin facing severe unemployment, such as McAdam, N.B. which recorded an unemployment rate approaching 50% (McAdam Economic Development Corporation, 1986).

In 1980, rural and urban populations were nearly equal in number. Some urban areas have had a steadily declining population, which includes Calais (Washington County Planning Commission, 1986) and St. Stephen. In the latter example, population loss is largely through out-migration of young working age groups, largely due to a lack of employment opportunities (Ogilvie, Ogilvie and Co. 1985).

3.1.3 ECONOMIC ACTIVITIES

Economic activity in the Basin includes forestry, pulp and paper processing, fisheries research, tourism/recreation, agriculture, government services and other support services. General economic decline in the Basin has led to more emphasis on tourism and recreation in an effort to reduce high unemployment levels through economic diversification. The designation of the St. Croix Waterway Recreation Area and the St. Croix as a Heritage River are expected to encourage this activity.

In the past three decades, there has been a significant decline in economic activity in the Basin. In the 1950s, C.P.R. employed 650 people in McAdam, New Brunswick - it now employs 10. Examples of plant closures occurring within the past five years include the Georgia -Pacific Plywood mill in McAdam, New Brunswick, the Starkist Tuna Plant in Bayside, New Brunswick (which re-opened in 1987 but with reduced workforce), and the Texas Steel Plant in St. Stephen, New Brunswick. These closures led to the loss of approximately 1,000 jobs. Principal employers now in the Basin are: The Georgia-Pacific Corporation in Baileyville-Woodland, Maine; Fisheries and Oceans Canada in St. Andrews, New Brunswick; the Huntsman Research Laboratory (Marine) in St. Andrews, New Brunswick; Ganong Brothers Ltd. in St. Stephen, New Brunswick; the Flake Board Company in St. Stephen; tourism (principally in St. Andrews); government services (customs, etc.); and other service industries.

The following provides further detail on the active economic sectors in the Basin:

3.1.3.1 Forestry - Forest Products

The Georgia Pacific Corporation (G-P), the largest company in the area, employs over 1,200 people in its forest harvesting and wood processing operations. G-P operates a pulp and paper mill, a wafer board mill and a Chip-N-Saw Mill in Baileyville-Woodland, Maine, which together produce paper products, construction materials, and chemical products worth approximately $14.9 million (U.S.) annually (QLF-ACE, 1986). These plants require 2.8 million m^3 (783,000 cords) of wood annually, of which 50% is produced by G-P and the balance purchased from private producers in and around the Basin. Of the total wood requirements, 1.9 million m^3 (532,000 cords) or 68%, is hardwood. Most of G-P's 328,000 ha (810,000 acres), in southwestern New Brunswick and southeastern Maine, lie within the St. Croix River Basin, making it the largest landholder (approximately 75% of the drainage area) in the Basin (Figure 3.2 - Georgia-Pacific Corporation Land Holdings). The company also owns the water rights to these holdings and regulates the water levels of sections of the St. Croix River at and above Woodland on both sides of the International Border. G-P harvests its timber on a sustainable yield basis in which 98% of its timberland is harvested under a partial cut program (smaller trees are left uncut), and the remaining 2% under a clear cut program with subsequent reforestation. Reforestation is achieved by planting 2.0 million company grown seedlings annually (9,000 ha or 23,000 acres reforested to date). G-P also provides assistance to 250 private wood producers in areas of forest management.

Other wood-related industries include several small sawmills and the Flake Board Company in St. Stephen. The latter employs approximately 170 people and purchases its wood requirement from local private wood producers.

3.1.3.2 Power Generation

Sixty percent of G-P's power requirements are met by its hydroelectric power facilities at Grand Falls and Woodland and 40% through thermal power generation at G-P's Woodland facility.

Since this report is concerned with water, the hydroelectric power capacity and production which occurred in the Basin in 1985 is summarized in Table 3.3.

TABLE 3.3

HYDROELECTRIC GENERATING FACILITIES 1985

Plant (Owner)	Generated (MWH)	Capacity (KW)
Milltown (N.B. Power)	19,500	3,100
Woodland (G-P)	31,260	9,430
Grand Falls (G-P)	33,620	9,480
TOTAL	84,380	24,160

The approximate value of the power produced in 1985 is $4.0 million (Cdn). The Milltown Dam produced 19,500 MWH to which an average power price of $36.00/MWH has been assigned (S. Ismael, New Brunswick Power, personal communication), equalling approximately $700,000. In the case of Georgia Pacific Corporation, had it been necessary for the company to purchase its power requirements, it is estimated that G-P would have had to pay approximately $36.00 (U.S.)/MWH to Eastern Maine Electric, which amounts to $2.3 million U.S. annually. These statistics do not account for variable pricing - the value of the power produced is likely greater than that estimated. With varying market conditions determined by such things as the price of oil, other hydro producers, weather changes drought, etc., power production and the value of energy is variable.

3.1.3.3 Agriculture

The St. Croix Watershed consists of approximately 423 000 ha, of which roughly 60% is on the United States side of the international boundary. A little less than 10% of the basin's land is utilized for agricultural purposes, which is a distant second to that utilized for forestry activities (80%). Agricultural activities are varied in nature and agricultural land is in a transitional state.

Historically, there was more agricultural land use than there is in the St. Croix River Basin at the present time. The many shrub covered fields are evidence of the decline of the agricultural sector. Farm activity is scattered throughout the watershed on till, glacial fluvial outwash and marine sediments. However, the agricultural capability is limited to CLI class 3 or less with the main agricultural cover being grass.

It was observed that throughout the watershed, land is converting to cover types other than those associated with agricultural pursuits. From St. Stephen to Princeton to North Lake, there are examples of changes in the landscape. Abandoned fields now are covered with shrubs and/or trees of varying heights. There are also scattered farms of the 'back to the land' type appearing, that may, in time, have a marked effect on slowing the abandonment of, or clearing of new areas for farming.

Farmland abandonment or the conversion of agricultural land to other uses is the result of several factors. As documented by the Resource, Conservation and Development (RC&D) committees (QLF-ACE, 1986), the following problems are faced by the Washington County agricultural community:

1. Production costs are out stripping the farm returns.
2. Transportation costs are increasing for materials moving to and from the farmstead.
3. Farmers cannot expand nor can potential farmers afford to start an operation due to the lack of low-interest venture capitol.
4. A reasonable tax structure for agricultural is needed.
5. Pressure exists to develop agricultural land for other activities.
6. The conversion of transitional land toward forest species of less economic value.

Traditional activities include dairy, livestock and poultry operations. The extent of the land for special uses, such as orchards, is very limited. Only two orchard areas were detected during air reconnaissance by light aircraft.

With the abandonment of farmland, there is a potential for the development of additional land for blueberry production. There are indications that this is occurring in the North Lake, New Brunswick area and in the northwest part of the basin near Weston, Maine.

In the Maritime Provinces, blueberry production on abandoned farms, and to a lesser extent, on forest cutovers, is being encouraged. This is not likely to occur on the majority of cutovers in the St. Croix Watershed due to the large area controlled by Georgia-Pacific Corporation. G-P must ensure the regeneration of the commercial tree species on their holdings, as opposed to a berry crop, to remain a producer of forest products.

Discussion with Statistics Canada representatives supports the conclusion that blueberries represent a major increase in the agricultural sector in the New Brunswick part of the basin. It is the blueberry harvest that is responsible for most of the 14% increase in the agricultural products sold on the Canadian side of the basin between 1970 and the 1980. Details of changing agricultural trends and the results obtained from an analysis of Landsat imagery are discussed above in Section 2.0.

In conclusion, agricultural activities in the St. Croix River Basin do not pose a serious threat to water quality and water quantity in the basin. It is likely only that blueberries will increase in importance as a cash crop in the study area as a spin-off from the nearby commercial wild blueberry industry.

3.1.3.4 Recreation

Recreation and tourism make significant contributions to the Basin economy. The St. Croix River Basin can be divided into four physiographic zones which provide unique environments for various recreational and tourist activities. A summary of the specific recreational activities offered within each zone is provided below:

Zone 1 - The Interior Lake Region

Winter

- snowmobiling
- cross-country skiing
- snowshoeing
- ice fishing
- small game trapping
- skating

Summer

- boating
- fishing
- hiking
- camping
- swimming

Zone 2 - The North-Grand-Spednic Lake System

Winter

- snowmobiling
- skating
- ice fishing

Summer

- boating
- fishing
- canoe-camping
- swimming

Zones 3/4 - The St. Croix River

- down river canoeing and kayaking
- canoe-camping

Zone 5 - Tidewater and Estuary

- boating
- fishing
- swimming
- sightseeing

(DPA Consulting Ltd., 1984)

(a) Angling

Angling is the principal recreational pursuit in the St. Croix River Basin (QLF-ACE 1986). Principal fish species include small mouth bass, land-locked salmon, lake trout, white perch, chain pickerel, and brook trout. There are usually large numbers of gaspereau (alewives) and small numbers of salmon in the lower reaches of the River. Residents and non-residents of the area are attracted by this sport fishery with residents tending to fish for trout and land-locked salmon, while non-residents (from the northeastern U.S. and Central Canada) are attracted by the small-mouth bass. The total number of anglers using the St. Croix River Basin has not been established, but a survey indicated that Grand Lake Stream had approximately 1,350 angler days in 1986, while winter aerial counts of anglers on West Grand Lake indicated approximately 1600 angler days. It was estimated that summer use of the West Grand Lake would be 6 to 8 times this winter value. On the Eastern Branch and mainstem of the St. Croix River, a recent survey, conducted between May and September, 1986, of 1300 people using the St. Croix River, indicated approximately 800 were there for angling purposes in addition to other pursuits (QLF-ACE, 1986). Therefore, an estimate of 13,000 angling days per year would be conservative since it would not include all anglers in all sections of the Basin, for all seasons, but this value would help in establishing a rough estimate of the total expenditures made by anglers in the Basin. The survey of 1,300 people above spent approximately $100,000 or approximately $75 U.S. per person (which is approximately $100 Cdn./person/day, charged by outfitters/guides, including accommodation). Applying this to the total number of 13,000 angler days produces an approximate value of $1,300,000 (Cdn.) per year. This value does not include the number of Basin residents who fish and who obviously would have spent lesser amounts of money on their fishing trips.

(b) Canoeing/Kayaking

The St. Croix River has some of the best canoeing routes in Eastern North America providing a full range of river conditions. Over 6,000 canoeists used the river in 1982 (mostly U.S. canoe clubs), with Vanceboro most often being the departure point. Several campsites are located on the canoe routes, but are not sufficient to accommodate peak numbers (DPA Consulting Ltd. 1984). An estimate of the total expenditures by this group is not available.

(c) Camping

There are well over 200 campsites within the basin which include those in the North Lake Provincial Park (60 campsites), Spednic Lake (36 campsites), the Provincial Campground at Oak Bay (near St. Stephen, with 111 campsites), and 20 primitive campsites in the lakes region (DPA Consulting Ltd., 1984). The number of people using these facilities is not available, but some of the primitive campsites have been insufficient to meet peak demand, while provincial parks have an average occupancy of approximately 40% (Underwood McLellan, 1985).

(d) Other

Other recreational activities in the basin include recreational vehicle use, cross-country skiing, hunting and boating. Hunting attracts people from northeastern U.S. and central Canada, who usually pay approximately $100/day for guides. Ducks Unlimited has five waterfowl/

wetlands enhancement projects currently under development, amounting to approximately 750 ha (1,870 acres). To date there has been only a marginal waterfowl population in the basin.

Cottages were first constructed in the 1930s, and are located mainly on East Grand Lake, Spednic Lake and Skiff lake.

3.1.3.5 Tourism

Tourism is largely centred in the southeastern part of the basin at St. Stephen/Calais and St. Andrews. In St. Andrews, of non- resident tourists, 58% are from the U.S., 21% from Ontario, and 15% from Atlantic Canada. These people are attracted to the region by its historic sites such as St. Croix Island, International Historic Monument, site of the first European settlement north of Florida - 1604, the Loyalist heritage and architecture, the landscape, the Maritime life style, and other attractions such as the Huntsman Marine Laboratory and Aquarium which has approximately 22,000 visitors annually (Underwood McLellan, 1985). The dollar value of this industry is not available, however, it is the mainstay of the St. Andrews area economy.

An interesting observation, which could be related to recreational potential in the basin, is the fact that the Calais-St. Stephen border crossing is the sixth busiest in the United States (WCRPC' 1986).

3.1.3.6 Food Processing

Food Processing is now limited to Ganong Brothers Ltd. in St. Stephen, a confectionery manufacture which employs approximately 260 people. The Starkist Tuna plant in Bayside, New Brunswick, the only other major food processor in the area, closed indefinitely in late 1985, with a loss of 400 jobs but re-opened in 1987 with a reduced work force.

3.1.4 WATER WITHDRAWAL AND USE

The domestic, industrial/institutional, and tourism/recreation sectors of the Basin economy have diverse water requirements, some of which are described in the following. Associated problems and conflicts arising from these uses are also discussed.

3.1.4.1 Municipal (Domestic)

Tables 3.4 and 3.5 summarize municipal water use and treatment respectively. Approximately half the Basin population is served by public water supply systems, while the balance is dependent on domestic wells or private water supply systems (e.g. trailer court systems).

(a) St. Andrews, New Brunswick

Chamcook Lake, 7 kms from the Town of St. Andrews, used as a source for the municipal water supply, has proven to be more than adequate in meeting demand for a population of 1,800, with a designed flow demand of 2,900 m^3/day, and an average flow demand of 1,970 m^3/day. In planning for maximum use of the resource, 22% of the flow would be allotted to the Town of St. Andrews, 25% to the Champlain Industrial Park (main user was the Tuna Processing Plant), and 49% to the International Atlantic Salmon Foundation in Chamcook. Proposed aquaculture activities, using Lake Chamcook as a water source, and requiring an amount equal to, or more than that of the Atlantic Salmon Foundation, may prompt water reapportionment by the Province of New Brunswick. The Town has also had problems with watershed protection. Many of the approximately 70 cottages located within the Chamcook Lake watershed are situated near the municipal water intake, posing a threat to water quality. Water treatment is generally limited to disinfection before distribution.

Town waste treatment is achieved through use of a waste stabilization pond (MUD, 1986).

(b) St. Stephen, New Brunswick

The St. Stephen water system provides water to approximately 9,500 people, which includes about 4,500 people in Calais, Maine (50% of the water supply is provided to Calais). The water supply is derived from a well sunk in the alluvium of Dennis Stream north of the town, with an average flow of approximately 5,500 m^3/day, which has proven to be an adequate supply (CBCL Ltd., 1984). However, there is concern about maximum yield of the well, as well as the susceptibility of water supply to infiltration contamination of the alluvium (N.B.D.O.E., 1977).

Municipal waste treatment is done through both a waste stabilization pond and secondary treatment (MUD, 1986). Environment Canada reports effluent is high in fecal coliform. Chlorination is being considered.

TABLE 3.4

WATER USE/WITHDRAWAL

Municipality	Average Daily Flow (m^3)	Population Served	Water Use m^3/day Domestic	Indust/Inst	Other	Source
Town of St. Andrews, N.B.	1970	1760	1182	690	99	Surface
Town of St. Stephen, N.B.	5445	5069	3267	1634	545	Ground
Village of McAdam, N.B.	N/A	480	N/A	N/A	N/A	Ground
City of Calais, Me.	2270	4456	1750	520	-	Town of St. Stephen, N.B.
Baileyville (Woodland) Me.	1520	2200	1520	-	-	Ground

References: QLF-ACE, 1986;
CBCL Ltd., 1984

TABLE 3.5

SEWAGE TREATMENT

Municipality	Average Daily Flow (m^3)	Population Served	Treatment Method (#People) None	Primary	Waste Stabilization Pond	Secondary	Tertiary
Town of St. Andrews, N.B.	2000	1760	-	-	1760		
Town of St. Stephen, N.B.	2836	5018	102	-	3226	1792	
Village of McAdam, N.B.	900	1600	56	-	-		1544
City of Calais, Me.	810	4041	-	-	-	4041	
Baileyville (Woodland) Me.	400	2200	-	-	-	400	

References: MUD, 1986; QLF-ACE, 1986;

(c) McAdam, New Brunswick

McAdam has three public water systems: (i) the fire protection system is connected to the CPR 0.5 million litre storage tank (quality of this groundwater is not suitable for domestic consumption because of petroleum contamination); (ii) the domestic industrial system, recently constructed, is groundwater supplied, and currently serves the McAdam Industrial Park and 60 households; and (iii) New Brunswick Housing Corporation system constructed to service a mobile home park and a housing area of a land assembly project (N.B.D.O.E., 1980).

With an estimated average daily per capita consumption of 545 litres (120 i gals., N.B.D.O.E. 1980), total McAdam domestic water use is approximately 0.8 million litres/day. 70% of the population continues to derive its water from dug or drilled wells. However, there is a chronic water quality problem arising from both sewage and petroleum contamination in many of these wells. This problem prompted the development of the domestic/industrial supply system described above. To date, 60 households have been connected and another 20 will presently be added. There remain approximately 1,100 people who use private wells. No surface water sources are used. McAdam Lake, adjacent to the village, has serious water quality problems arising from sewage contamination. Efforts to modernize sewage treatment have resulted in the construction of a tertiary sewage treatment plant which services approximately 1,550 people.

(d) Calais, Maine

The Calais Water Department, serving about 4,500 people, purchases its water requirements of 2,300 m^3/day from St. Stephen, New Brunswick, and, in turn, supplies Milltown (part of St. Stephen) with its water needs.

The Calais sewage treatment system has a licensed flow of 2,800 m^3/day, but discharges only 30% of this. It has capacity problems during storm runoff in which it may receive quadruple its normal load. This problem is being remedied. Calais' BOD limit has not been exceeded in 5 years (QLF-ACE, 1986).

(e) Baileyville-Woodland, Maine

For clarification, Baileyville-Woodland is known as the "Town with Two Names". Most maps and the post office carry the name "Woodland" as the community name, but the town was incorporated in 1828 under the name of "Baileyville". The surrounding township in Washington County is also known as Baileyville. The Baileyville-Woodland water and sewer systems are independent of those owned by Georgia Pacific. For sewage treatment, the Baileyville plant has a licensed capacity of 1,100 m^3/day, of which only 35% is currently discharged. This plant has generally been in compliance (QLF-ACE, 1986). The Town has identified watershed protection as a high priority problem and is seeking assistance from the Maine DEP and U.S. Geological Survey through representations to the Regional Planning Commission's Water Quality Committee. The town intends to extend its sewer lines to include a greater number of residents in its hook-up. The Baileyville Utilities District is reported to serve 2,200 water consumers and uses 1500 m^3/day.

In general, municipal infrastructure is sufficient to meet the foreseeable needs of the urban population within the Basin. However, all municipalities currently face problems with watershed or groundwater protection.

3.1.4.2 Industrial/Institutional

The major water user in the St. Croix River Basin, the Georgia Pacific Corporation (G-P) located at Woodland, Maine, has its own water supply and treatment infrastructure. G-P is licensed by Maine D.E.P. to discharge up to 150,000 m^3 (40 million U.S. gallons) of process water per day. On average, however, it discharges only 67% of this. Waste water from processing is treated with a primary treatment clarifier which has a volume of 9,500 m^3 (2.5 million U.S. gallons) with a 3-hour retention time, and a secondary treatment system (treating 95,000 - 114,000 m^3/day (25-30 million U S. gallons daily) of total effluent. Twenty aerators are used in two aeration lagoons with a capacity of 1.3 million m^3 (350 million U.S. gallons) before treated water is piped back to the river.

There have been water quality problems below the G-P Woodland mill due to equipment breakdown and spills. These problems are now being remedied. Water quality, in general, has improved in the past two decades, to the point that anadromous fish are once again being introduced to the St. Croix River in the form of Atlantic salmon.

The other major industrial use of water is for hydroelectric power generation. As indicated previously, there were approximately 84,000 MWH generated in 1985. Georgia Pacific is responsible for maintaining flow levels under a company designed, International Joint Commission approved, rule curve. While maximum and minimum level guidelines have been established, and adhered to in general, fluctuations within these can create problems for other water users such as cottage owners, fishermen and canoeists. The IJC conducted a survey in 1973 as a result of complaints of fluctuating water levels, particularly on Spednic Lake. The following are the results:

> Access - All respondents cited difficult and hazardous boat access during summer draw-down period. Boating mishaps and damages due to low water levels were also reported.
>
> Low Water Table - Several respondents experienced domestic water shortages during low water periods; wells ran dry and water lines froze in winter.
>
> Fishing - Nearly unanimous agreement (85%) that changes in water level affect smallmouth bass and salmon populations; steady declines attributed mainly to exposed spawning beds and fingerlings trapped in pools. Comments based on average of 21.8 years experience on the lake per respondent.
>
> Erosion - 75% reported serious bank erosion, damage to shore, trees, etc. due to water fluctuations in winter resulting in ice pushing upon the shore.
>
> Aesthetics - Few comments; although respondents favored raising levels in summer periods, they also feared that a more attractive lake might increase motor boats and development interest in the area.
>
> Commercial Loss - Though difficult to ascertain, commercial camp operators estimated losses of $1,500 to $2,000 per annum due to decreased use during low water periods. Others (e.g. local merchants) remarked that poor lake conditions adversely affect the local economy through decreased tourism (QLF-ACE, 1986).

In summarizing G-P's task of maintaining water levels, the St. Croix Waterway Joint Advisory Commission (1986) says:

> The Georgia-Pacific Corporation has the unenviable task of performing a delicate balancing act, servicing both Georgia-Pacific's interest in the production of hydro-energy and public interest in managing recreational resources while maintaining International Joint Commission standards ....
>
> Water flowage rates, elevations and water quality are major issues in the discussion of the St. Croix Waterway. Water levels and water quality are of critical importance, not only to the continuity of the plant and animal species, geological features and other valuable river resources such as shoreline archaeological sites, but also for an outstanding recreational experience ....

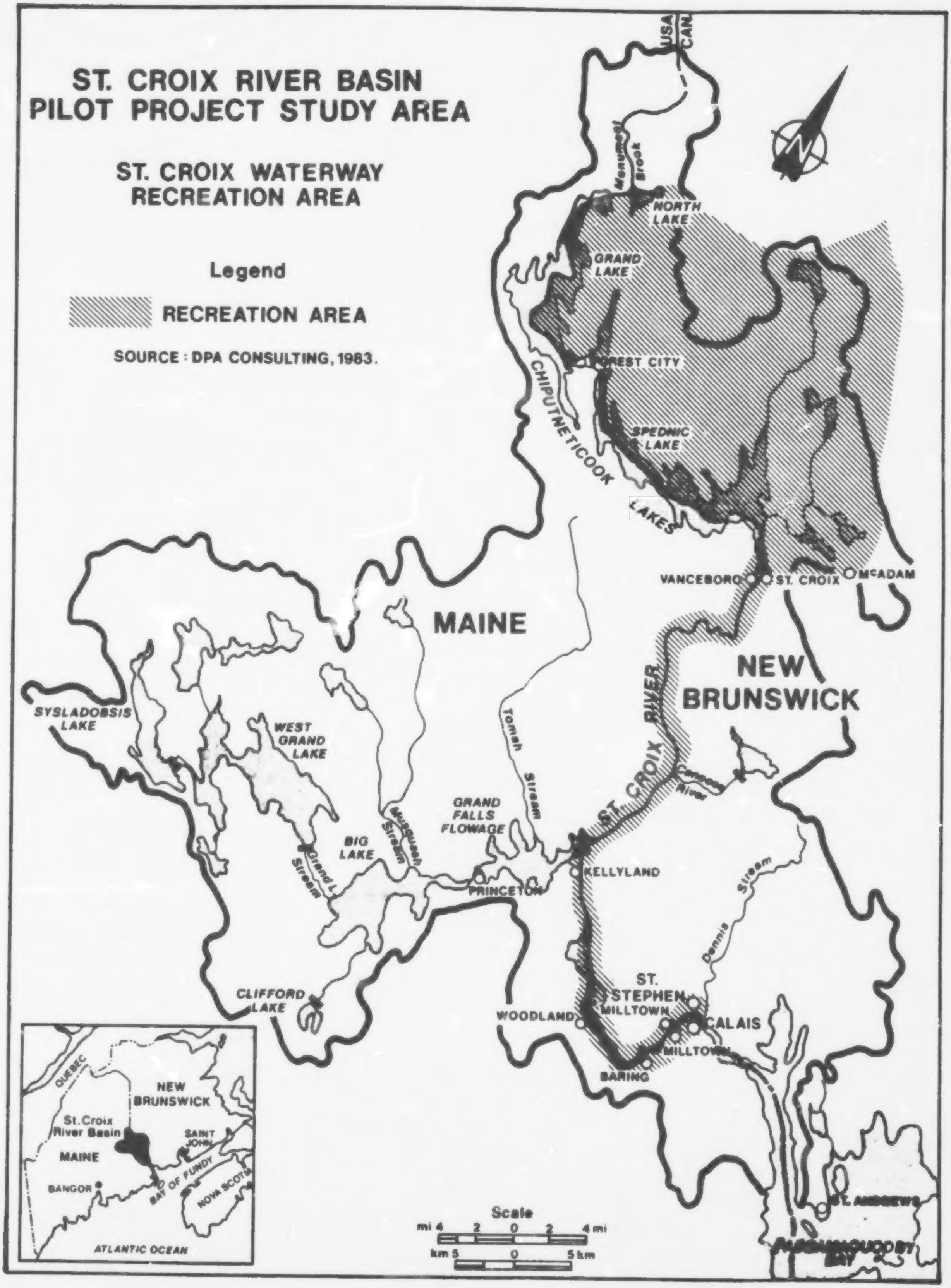
It must be noted that the Georgia-Pacific Corporation has complied with IJC standards. The IJC will be reviewing the minimum water level requirements for the St. Croix Waterway and a report is expected to be completed within two years. The St. Croix Waterway Joint Advisory Commission has concluded that many variables must be considered in determining appropriate water levels, and that this issue will have to be readdressed by the permanent co-ordinating body in conjunction with other government agencies such as the IJC.

3.1.4.3 Recreation/Tourism

Economic decline in the Basin prompted moves to develop the recreational/tourism potential of the area. In 1982, a specific area within the basin was established by New Brunswick Government Order-in-Council under the Community Improvement Corporation Act as the St. Croix Waterway Recreation Area (Figure 3.3). Figure 3.4 illustrates the current jurisdictional area established by the St. Croix Waterway Joint Advisory Commission and takes in the Northern Lakes up to the river headwaters at the end of Monument Brook, and generally extends 61.0 m (200 ft.) from the highwater mark on the New Brunswick side and 76.2 m (250 ft.) from the highwater mark on the Maine side of the river. The SCWRA extends to Princeton in the west side and south to Passamaquoddy Bay. Specific boundaries are described in the Report of the St. Croix Waterway Joint Advisory Commission (1986).

The St. Croix Waterway Joint Advisory Commission was further established to advise the State of Maine and the Province of New Brunswick on joint management issues involved in multiple uses of the St. Croix River Basin. Their 1986 report provides a basis on which to also involve both Federal governments and the I.J.C.

Another report (DPA Consulting Ltd., 1985) presented additional observations and recommendations, including the suggestion that the number of campsites available to canoeists and boaters should be more than doubled to accommodate 600 people/day with minimal impact to the area; and the SCWRA carrying capacity could be 650 people/ day. The report further suggests that infrastructure should be established in the Village of McAdam, New Brunswick, to support expanded recreational use of the area. This infrastructure includes, for example, the construction of a User Information Centre, trail systems, interpretation centre, Outward-Bound School, expanded and improved camp facilities; development of archaeological sites, canoe routes; and expanded private facilities, e.g. outfitters' lodges. These suggested improvements have yet to be carried out.



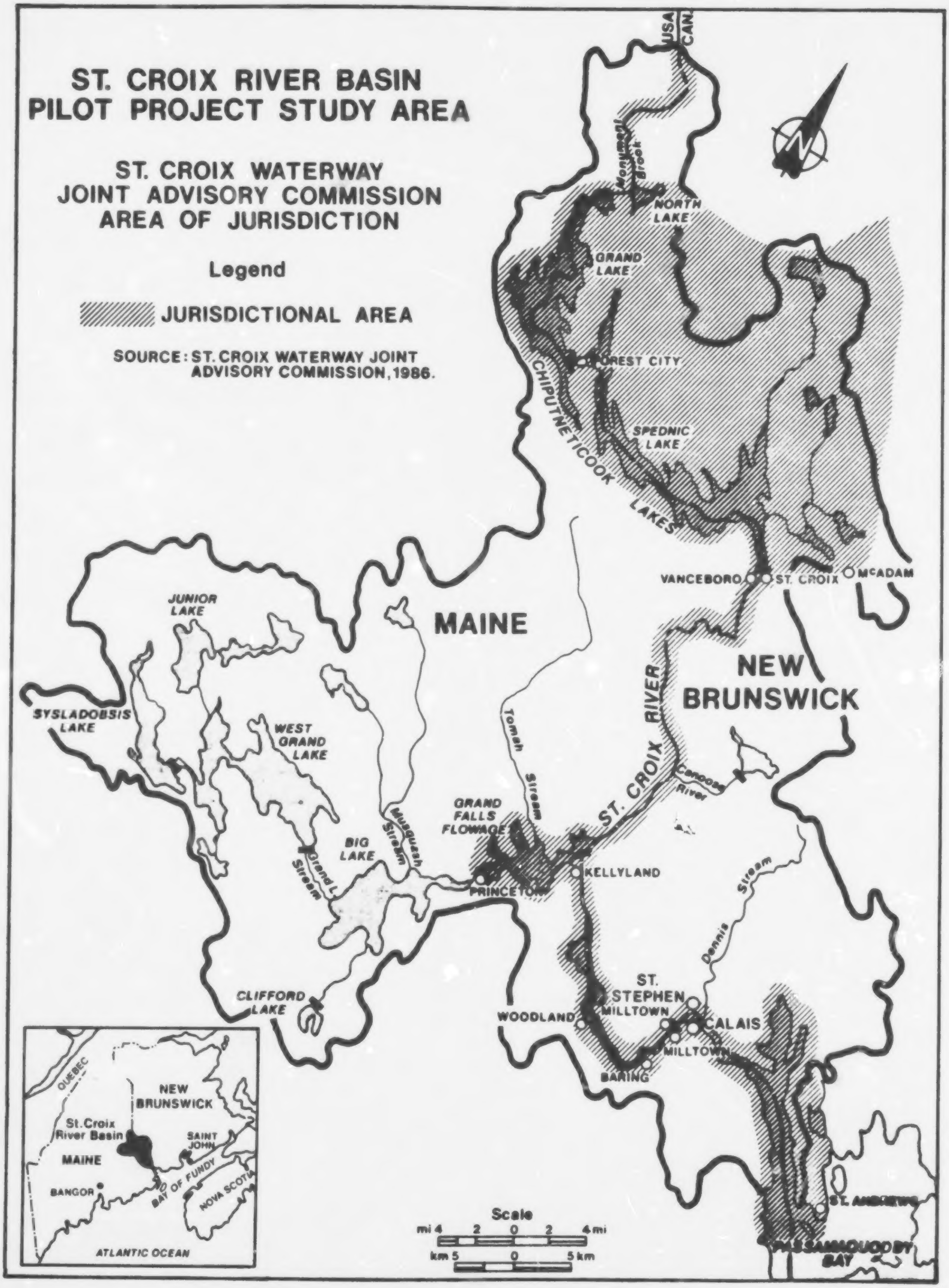
ST. CROIX RIVER BASIN PILOT PROJECT STUDY AREA

ST. CROIX WATERWAY RECREATION AREA

SOURCE : DPA CONSULTING, 1983.

Legend
▨ RECREATION AREA
USA
CAN
Monument Brook
NORTH LAKE
GRAND LAKE
FOREST CITY
CHIPUTNETICOOK LAKES
SPEDNIC LAKE
VANCEBORO
ST. CROIX
McADAM
MAINE
NEW BRUNSWICK
ST. CROIX RIVER
Canoose River
SYSLADOBSIS LAKE
WEST GRAND LAKE
BIG LAKE
Grand L. Stream
Musquash Stream
GRAND FALLS FLOWAGE
Tomah Stream
PRINCETON
KELLYLAND
Dennis Stream
CLIFFORD LAKE
WOODLAND
ST. STEPHEN
MILLTOWN
CALAIS
MILLTOWN
BARING
ST. ANDREWS
PASSAMAQUODDY BAY
Scale
mi 4 2 0 2 4 mi
km 5 0 5 km
QUEBEC
NEW BRUNSWICK
St. Croix River Basin
MAINE
SAINT JOHN
BAY OF FUNDY
BANGOR
NOVA SCOTIA
ATLANTIC OCEAN

Figure 3.3



ST. CROIX RIVER BASIN PILOT PROJECT STUDY AREA

ST. CROIX WATERWAY JOINT ADVISORY COMMISSION AREA OF JURISDICTION

SOURCE: ST. CROIX WATERWAY JOINT ADVISORY COMMISSION, 1986.

Legend
▨ JURISDICTIONAL AREA
USA
CAN
Monument Brook
NORTH LAKE
GRAND LAKE
FOREST CITY
CHIPUTNETICOOK LAKES
SPEDNIC LAKE
VANCEBORO
ST. CROIX
McADAM
MAINE
NEW BRUNSWICK
ST. CROIX RIVER
Canoose River
Tomah Stream
JUNIOR LAKE
SYSLADOBSIS LAKE
WEST GRAND LAKE
BIG LAKE
Grand L. Stream
Musquash Stream
GRAND FALLS FLOWAGE
PRINCETON
KELLYLAND
Dennis Stream
ST. STEPHEN
MILLTOWN
WOODLAND
CALAIS
MILLTOWN
BARING
CLIFFORD LAKE
ST. ANDREWS
PASSAMAQUODDY BAY
Scale
mi 4 2 0 2 4 mi
km 5 0 5 km
QUEBEC
NEW BRUNSWICK
St. Croix River Basin
MAINE
SAINT JOHN
BANGOR
BAY OF FUNDY
NOVA SCOTIA
ATLANTIC OCEAN

Figure 3.4

Some other initiatives have also been undertaken. Part of the St. Croix Waterway Recreation Area on the Canadian side of the border has been nominated by the New Brunswick Government for inclusion in the Canadian National Heritage River System (Figure 3.5).

The St. Croix River was found to have natural, historical and recreational values of national significance and was accepted as a candidate river in 1984. A development plan must be prepared by the nominating organization before the river can be designated. With $150,000 in funding from both the Canadian Heritage River System and the New Brunswick government, studies were initiated by New Brunswick to fulfil designation requirements. These studies included archaeological, ecological, flood and tourism/recreation surveys; a recreational waterway inventory, a jurisdictional review, and other background reports. Designation is still subject to preparation of a development plan.

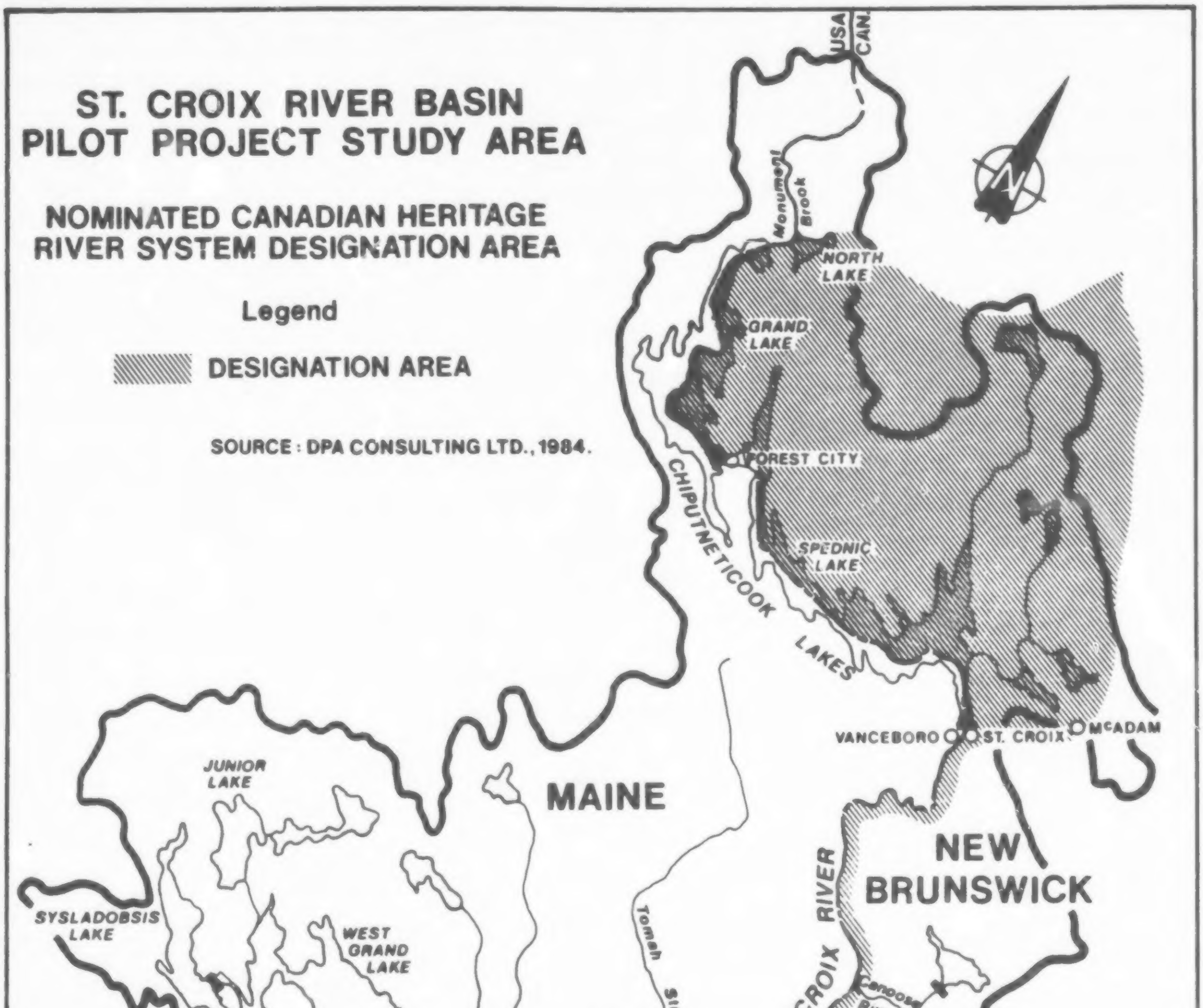
Parallel designations or special considerations of the St. Croix River by the State of Maine are evident through the designation of the St. Croix as a Type "A" river in 1982. This designates the river as one possessing a composite natural and recreational resource value of greater than state significance. Also, the Maine Rivers Act provides special protection for the St. Croix River because it is part of the international boundary (QLF, 1986).

The above activities serve to highlight the growing importance the St. Croix River Basin has in serving regional recreational requirements. With this growing importance, there will be, in all likelihood, increased conflict between historic use (industrial and hydro power) and recreational uses. The main point of contention will be, as before, fluctuating water levels, at least the question of what levels are established in competition with minimum flow requirements.

3.1.4.4 Fisheries

For optimal production of fish, conditions are required with good water quality, little fluctuation in water level, little habitat competition, and unhindered passage. Socio-economic activity within the St. Croix River Basin affects all of these to varying degrees.

During the mid-May to mid-June spawning period for small mouth bass, for example, water level fluctuations of 30 cms will cause spawning bed abandonment. In Spednic Lake, fluctuations of this magnitude are


USA
CAN.
Monument Brook
NORTH LAKE
GRAND LAKE
FOREST CITY
CHIPUTNETICOOK LAKES
SPEDNIC LAKE
VANCEBORO
ST. CROIX
McADAM
MAINE
NEW BRUNSWICK
JUNIOR LAKE
SYSLADOBSIS LAKE
WEST GRAND LAKE
BIG LAKE
Grand L. Stream
Musquash Stream
GRAND FALLS FLOWAGE
Tomah Stream
ST. CROIX RIVER
Canoose River
KELLYLAND
PRINCETON
Dennis Stream
CLIFFORD LAKE
WOODLAND
ST. STEPHEN
MILLTOWN
CALAIS
MILLTOWN
BARING
ST. ANDREWS
PASSAMAQUODDY BAY
QUEBEC
NEW BRUNSWICK
St. Croix River Basin
SAINT JOHN
MAINE
BANGOR
BAY OF FUNDY
NOVA SCOTIA
ATLANTIC OCEAN
Scale
mi 4 2 0 2 4 mi
km 5 0 5 km

ST. CROIX RIVER BASIN
PILOT PROJECT STUDY AREA

NOMINATED CANADIAN HERITAGE
RIVER SYSTEM DESIGNATION AREA

Legend

▨ DESIGNATION AREA

SOURCE : DPA CONSULTING LTD., 1984.

Figure 3.5

common, occurring in 7 of the past 15 years. Similar problems exist for land-locked salmon (QLF-ACE, 1986). Research has found that outfitters and guides perceive fish populations to be in decline because of fluctuating water levels (DPA Consulting Ltd., 1983). With expanded use of the St. Croix fisheries, there will probably be more concern expressed by anglers over changing water levels.

Exploitation of the fisheries of the St. Croix River has been and will one of the most important activities on the river for both recreation and commercial purposes. Lakes such as Spednic Lake are known throughout the U.S. and Canada for its excellent small mouth bass fishing as well as its land locked salmon. The regulated nature of the waterway has a significant influence on the populations of fish found there. The quality of the water and the access provided by control structures in the past has had a great influence on the fishery. This is particularly true of the anadromous species such as salmon (QLF-ACE, 1986).

In early times, the St. Croix River was considered to be one of the most prolific salmon streams on the east coast. For many years there were large annual catches with daily catches of 100 barrels reported in the Calais/St. Stephens area. However, by the mid 1800's, the migratory fishes were virtually cut off by the construction of dams from the freshwaters of the St. Croix River. By 1850, it was estimated that the total salmon annual catch did not exceed 200 fish (QLF-ACE, 1986).

Some efforts were made to provide for fishways in 1869. However, they were not maintained in later years with consequent diminished fish population.

In the past, water quality in some stretches of the river was not suitable for anadromous species, resulting in population decline to the point of virtual exclusion of fish life from some of these waters, at least on a seasonal basis. This was the case in particular in the stretch of river below Woodland.

Until recently, the river was used extensively for log drives which caused the river bottom to become congested with debris, water-logged wood and bark, especially high in BOD. More recent benthic surveys indicate this no longer to be a water quality problem, possibly due to this debris being flushed through the system, or covered by river sediments.

Water quality has improved continuously since the 1960's due to measures taken at G-P's Woodland plant for pollution abatement. As a result, the future for anadromous fish production appear to be assured, although there are problems to be overcome.

3.1.4.5 Water Use Concerns

Municipal water and sewer infrastructure capacities are sufficient for the foreseeable future. All municipalities are expressing concern over watershed and groundwater protection from contamination, and are actively seeking ways of ensuring that these supplies are protected.

The Georgia-Pacific Corporation, the main industrial water user in the basin maintains extensive waste water treatment facilities and is in the process of resolving equipment problems which resulted in several instances of water pollution below Woodland in 1980 (QLF-ACE 1986). G-P is required to maintain water levels in Spednic Lake, and have had to balance their power requirements with low water conditions in the past two years, and the requirements of other water users in the basin. G-P has managed to operate within required levels and has maintained minimum flow requirements.

With the increased use of the basin as a recreational facility, there will probably be increased incidence of complaints by non-industrial users over fluctuating water levels, even if they are within IJC guidelines.

3.1.5 PROPOSED ECONOMIC DEVELOPMENT

3.1.5.1 Industrial

There is concensus among the municipalities and planning organiations within the basin that economic stimulus has to occur to effect growth.. Growth in the industrial sector is not expected to be significant. The Georgia Pacific Corporation's Woodland Mill's outlook is stable for the next 10 to 15 years, depending on a projected spruce-fir shortage. Since G-P is involved in a major capacity addition in the southern U.S., it is unlikely that there will be any major changes to the Woodland mill that would add jobs in the near future. However, the company received approval in 1986 for a $75 million modernization project that includes a new recovery boiler to replace two less efficient ones, and may add a new paper-making machine in the next few years. In 1985, it announced construction of a new cut-size machine which would cost $85 million and create 16 permanent jobs (QLF-ACE, 1980). These developments will probably have minimal impact on the water resources in the basin.

3.1.5.2 Hydroelectric Power Development

Should the price of fossil fuels rise drastically, several sites on the St. Croix may be attractive for hydroelectric development. In 1981, the New England River Basin Commission identified nine existing dams with redevelopment potential for a total of 6.9 MW of power. Five of these sites passed an engineering practicality test (1.5 m head and >50 kw capacity) and four were economically attractive (70% plant factor, 15% interest rate, and an energy cost below 125 mls/kwh). The U.S. Army Corps of Engineers estimated that G-P's Woodland dam could increase capacity by 1.2 MW (QLF-ACE, 1986). These studies did not include an examination of demand or impact on social or ecological factors.

3.1.5.3 Tourism/Recreation

The consensus among planning and municipal organizations within the basin is, that if industrial development cannot be attracted to the area, the tourism/recreation industry should be expanded and diversified to attract travellers to stop over while in transit, and also attract recreation enthusiasts from other regions of North America and Europe. To achieve this, Calais has obtained funding for the construction of a floating dock to service pleasure craft and St. Stephen has begun shorefront development with an hotel slated for construction. McAdam is making the necessary presentations to initiate infrastructure construction to establish itself as a recreation centre in the St. Croix Waterway Recreation area. Designation of the St. Croix River as a Canadian Heritage River is pending subject to the preparation of a development plan.

While additional people will be attracted to the basin, there should be little impact on water resources. However, with increased recreational use of the St. Croix River Basin, there are several developing and potential issues which include: (i) conflicts between resident and non-resident user groups; (ii) conflict between various user groups; (iii) continued conflict between outfitters and campers over the use of area campsites; (iv) the effects of the regulation of Spednic Lake on canoeists along the main stem of the St. Croix River and on anglers using the Chiputneticook Lakes; and (v) increased potential for problems with litter and human waste disposal at primitive campsites along the waterway.

3.1.5.4 Fisheries

Since the 1960s, the quality of water has improved to the point that it appears that there will actually be a future for a fishery in the waterway. In the upper reaches of the St. Croix, things will continue as they are now, with the sport fishing of such species as smallmouth bass. Water quality in that portion continues to be good. In the lower reaches, the improving water quality will lead to increasing runs of salmon in the river. The Long Term Management Plan for the Diadromous Fisheries of the St. Croix River (Developed co-operatively by Fisheries and Oceans Canada, Maine Atlantic Sea Run Salmon Commission, Maine Department of Marine Resources and the Maine Department of Inland Fisheries and Wildlife) calls for the expansion of the salmon use of the river in the area above Grand Falls Flowage in the west branch of the river and its tributaries. This plan is going to place a need for greater control of water quality on the lower reaches of the river to ensure that the migrating salmon have adequate access to these reaches of the river. The stretch of river below Woodland usually provides sufficient dissolved oxygen to allow the migrating salmon to survive the upstream swim, but flow reductions due to equipment failures have caused fish kills due to reduced oxygen. Successful implementation of the management plan will require adequate dissolved oxygen levels in the St. Croix River's lower reaches below Woodland. The objective level of dissolved oxygen is 5 mg/l. Generally the quality of the water in this part of the river is adequate, however high temperatures and/or intermittent failure of waste treatment could result in fish kills in the lower stretch of the river, even though the required minimum flow requirement may not be technically violated.

Some additional problems may occur in implementing the plan for an increase in the migrating salmon stocks. The dams that are now in place on the St. Croix River present barriers to salmon migration upstream. Fishways have been constructed at each of these dams in the past. These include a pool and weir fishway at the Milltown powerhouse, Denil (or steep-pass) fishways at the Grand Falls and Woodland dams, and vertical slot fishways at Vanceboro and Forest city. The Milltown fishway was reconstructed in 1980 and has improved salmon passage. In general, these structures provide adequate passage for the upstream migration of fish, but efficiency is less than expected. When the fish are moving downstream, they can to some extent, take advantage of excess water being spilled during high flow periods. However, during the lower flow periods, the fish must pass through the turbines. No statistics exist for turbine mortality rates in the St. Croix River. However, there is no doubt that it will be a factor in the success of the reintroduction of salmon to this area.

3.1.5.5 Peat Extraction

Recent wetland inventories on both sides of the border indicat there is horticultural and fuel peat in commercial quantity and quality in the basin. Presently there are no commercial operations east of the St. Croix River, although there is one site having some potential and three sites exhibiting lesser commercial usefulness. The former is adjacent to Belle Lake in the northern tip of the basin. The potential exists for the extraction of horticultural peat (average humification of 1-3 on the Van Post scale) and subsequent extraction of the underlying fuel peat. To be commercially viable, a peat surface should be at least 250 ha (618 acres in area) (pers. comm. Jacques Thibault, N.B. Department of Natural Resources and Energy). This minimum size is needed to make the use of peat vacuum equipment cost effective. The scattered, small linear shaped peat bogs (topography/glacial controlled) and the fact the sphagnum is mixed with varying amounts of shrubs and wood and sedges, present conditions which discourage development of these peat bogs, especially when more attractive areas exist elsewhere in the Province.

Forty-seven areas containing peat deposits were surveyed in Washington County by the Maine State Peat Resource Evaluation Program, but of approximately 18 in the basin, only five appear to have commercial development potential, based on area alone.

There are only a limited number of peat bogs in the St. Croix Watershed that could be developed. Other peat bogs are located in closer proximity to markets and with a capital start-up cost in excess of one million dollars, no peat development is expected in the near future within the basin.

3.1.6 SUMMARY

Forestry and forest products manufacturing has been and will continue to be the mainstay of the St. Croix River Basin economy for the foreseeable future. With economic decline occurring in the manufacturing sector, resulting in unemployment rates of 30 - 50% in some areas, efforts have been made to expand and diversify the tourist/recreation sector. Efforts have also been made to enhance the inland fishery, including the reintroduction of anadromous fish species. An expanded fishery will, of course, facilitate the expanded recreational use of the basin, as well as increased commercial fishing. With increased recreational use of the St. Croix River Basin, there will probably be a problem with control of litter and other human generated wastes at campsites and roadsides which might increase the tension between various recreational users, and elicit further criticism of fluctuating water levels (DPA Consulting Ltd., 1983).

The establishment of the St. Croix Waterway Joint Advisory Commission, along with other management organizations and the IJC, will provide the means by which groups can seek redress for these problems.

Generally, the water resources of the basin are sufficient for current domestic and industrial requirements. While water quality below Woodland was poor in the past, this quality has improved to the point that anadromous fish can inhabit these waters and efforts are underway to reintroduce these fish species to the basin.

SECTION FOUR
SURFACE WATER HYDROLOGY

4.0 SURFACE WATER HYDROLOGY

4.1 INTRODUCTION

As previously stated, the St. Croix River Basin is heavily regulated for the production of hydroelectric power. However, riparian interests are protected by a series of State (Maine), E.P.A. (U.S.), and I.J.C. requirements as summarized below.

In view of the significant degree of water management activity in the basin, centred in large part on riparian requirements, significant hydrometeorological data networks are in place. These are summarized in Section 4.3. A preliminary analysis of the data is reported in Section 4.4. Through a comparison of "natural" and recorded mean monthly flows, the impacts of regulation on the river are discussed in Section 4.5 along with an assessment of the implications of several current proposals to alter riparian requirements.

4.2 ST. CROIX RIVER CONTROL REGULATIONS

The St. Croix River hydrological regime is subject to regulation of flows and water levels in the reservoirs which affect the overall runoff of the river and water quality.

The Georgia-Pacific Corporation has prepared an operations manual "Watershed Operating Procedures" (February 1982) which they use to operate the St. Croix River Basin to provide their hydroelectric needs within the required control regulations.

A summary of the control regulations will follow in order to clarify the operating procedures for the reader. Where applicable, the agency which requires the control regulation is indicated. Effective low water elevations, as governed by sill elevations on the control structure of the dam, are also indicated. Elevations and flow regulation values refer back to the original I.J.C. and E.P.A. orders and small variations from the G-P published data are attributed to metric conversion factors.

The established control regulations followed by Georgia-Pacific are summarized for the clarification of the reader as follows:

Grand (formerly East Grand) Lake Elevations and Discharges below Forest City Dam

Control Regulations: Federal Energy Regulatory Commission, I.J.C., and Maine Department of Fisheries and Game

Minimum Lake Elevation:	130.436 metres (427.94 ft.)
Maximum Lake Elevation:	132.570 metres (434.94 ft.)
Minimum Discharge below Dam:	2.12 m^3/s (75 cfs)
Drainage Area:	357 km^2 (138 sq. miles)

****

Spednic Lake Elevations and Discharges below Vanceboro Dam

Control Regulations: I.J.C.

Minimum Lake Elevations (1 Oct. to 30 Apr.)	113.233 metres (371.50 ft)
Minimum Lake Elevations (1 May to 30 Sept.)	114.757 metres (376.50 ft)
Maximum Lake Elevations	117.610 metres (385.86 ft)
Minimum Discharge below Dam	5.66 m^3/s (200 cfs)
Drainage Area	1080 km^2 (417 sq. miles)
Desired Summer Level for Cottage Owners	115.367 metres (378.50 ft)

****

Grand Falls Flowage Elevations and Discharge below Grand Falls Dam and Power Station

Control Regulations: Not specified

Effective Low Water Elevation	60.582 metres (198.76 ft)
High Water Elevation	62.106 metres (203.76 ft)
Minimum Desirable Discharge below Dam	24.1 m^3/s (850 cfs)
Drainage Area	3420 km^2 (1320 sq. miles)

****

St. Croix River Elevations and Discharges below Woodland Dam

Control Regulations: U.S.E.P.A.

Effective Low Water Elevation	42.468 metres (139.33 ft)
High Water Elevation	43.077 metres (141.33 ft)
Minimum Discharge below Dam	21.2 m^3/s (750 cfs)
Drainage Area	3500 km^2 (1350 sq. miles)

The minimum discharge of 21.2 m^3/s or 750 cfs below Woodland Dam is actually monitored at a U.S.G.S. hydrometric station located at Baring, Maine. This flow is required for pollution abatement purposes by the E.P.A., but the Maine D.E.P. has noted that this is daily mean discharge. In other words, this is the mean over a 24 hour period so fluctuations could occur over a large range and still conform to the flow requirements.

****

St. Croix River at Milltown Dam

The Milltown Dam is now owned by the New Brunswick Electric Power Commission which operates a power plant utilizing run of the river flow. No control regulations are in effect.

****

Sysladobsis Lake Elevations and Discharge below Dobsis Dam

Control Regulations: Not specified

Effective Low Water Elevation	91.757 metres (301.04 ft)
High Water Elevation	93.153 metres (305.62 ft)
Minimum Discharge below Dam	not specified
Drainage Area	161 km^2 (62 sq. miles)
Minimum Desirable Elevation for Cottage Owners (July and August)	92.239 metres (302.62 ft)

****

West Grand Lake Elevations and Discharge below Grand Lake Stream Dam

Control Regulations: Maine Department of Inland Fisheries and Game

Minimum Effective Lake Elevation	89.614 metres (294.01 ft)
Maximum Lake Elevation	91.876 metres (301.43 ft)
Minimum Discharge below Dam	2.83 m^3/s (100 cfs)
Drainage Area	580 km^2 (224 sq. miles)

****

Clifford Lake Elevations and Discharge below Clifford Dam

Control Regulations: Maine Department of Inland Fisheries and Game

Effective Low Water Elevation	67.949 metres (222.93 ft)
High Water Elevation	70.336 metres (230.76 ft)
Minimum Discharge below Dam	0.142 m^3/s (5 cfs)
Drainage Area	36.3 km^2 (14 sq. miles)

****

Canoose Flowage, Elevations and Discharge below Canoose Dam

Control Regulations: Not specified

Effective Low Water Elevation	94.110 metres (308.76 ft)
High Water Elevation	96.801 metres (317.59 ft)
Minimum Discharge below Dam	0.142 m^3/s (5 cfs)
Drainage Area	132 km^2 (51 sq. miles)
Desirable Elevation for Duck Hunters (October and November)	95.887 metres (314.59 ft)

****

4.3. AVAILABILITY OF HYDROLOGIC DATA

4.3.1 HYDROMETRIC STATIONS

Discharge and water level stations within the St. Croix River Basin are listed in Table 4.1 and their locations are shown in Figure 4.1. Period of record for each station is presented in Figure 4.2.

4.3.2 DISCHARGE RECORDS

Discharge has been recorded by the United States Geological Survey for the St. Croix River near Baileyville since 1919. The United States Geological Survey maintains three other stations: at Vanceboro which has recorded since 1928; at Grand Lake Stream where records are available from 1928 to date; and at Baring since 1959. A gauge at Spragues Falls was maintained by the United States Geological Survey for a few years near the turn of the century. The gauge near Baileyville was discontinued in 1983.

The Water Survey of Canada, Department of the Environment, has collected discharge records at the gauge below Forest City Dam (Forest City Stream) since 1968. Water Survey of Canada also maintains a gauge on Dennis Stream near St. Stephen. Dennis Stream is a tributary of the St. Croix River and is located near the mouth of the river. A gauge on Dennis Stream at Moores Mills has been discontinued. Outside the St. Croix River Basin, the Water Survey of Canada maintains a discharge station on Chamcook Stream at Little Chamcook Lake Outlet. Chamcook Lake is the water supply for the Town of St. Andrews as described in Section 3.1.4.

4.3.3 WATER LEVELS

Lake Levels have been recorded since 1915 at the four major storage reservoirs in the basin: Grand Lake, Spednic Lake, West Grand Lake and Grand Falls Flowage. The records for Grand Falls Flowage are intermittent prior to 1935, while those for the other three lakes are continuous from 1915 to date. These gauges were originally maintained by the Georgia-Pacific Corporation. The Water Survey of Canada took over the operation of Grand Lake, Spednic Lake and Grand Falls Flowage gauges in 1969, 1967 and 1980 respectively.

TABLE 4.1

ST. CROIX RIVER BASIN

HYDROMETRIC STATIONS

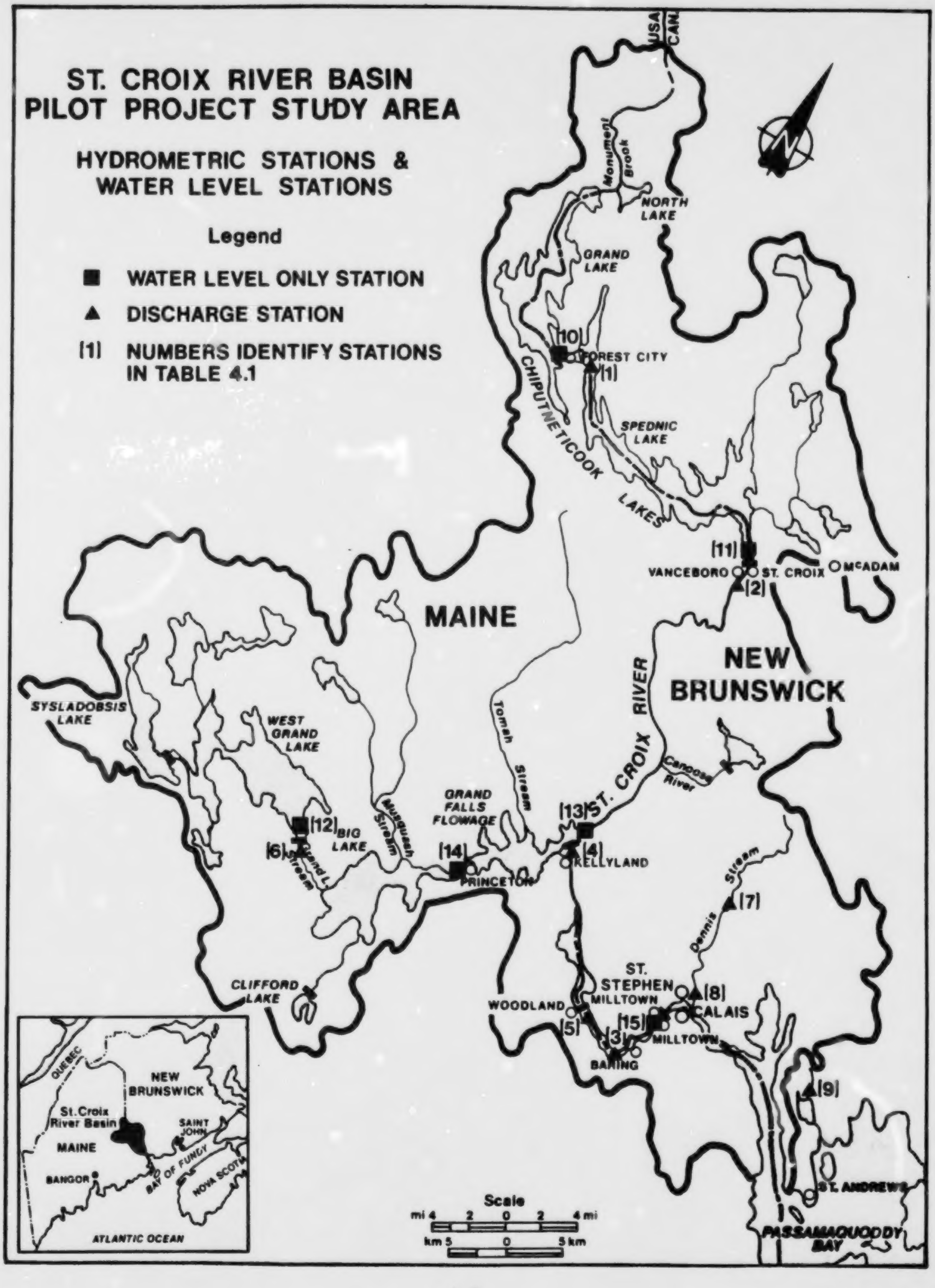
DISCHARGE

Station	Drainage Area (sq. km)	Period of Record	Location(a) Identifier
St. Croix River:			
- below Forest City Dam	357	1968 - date	(1)
- at Vanceboro	1080	1928 - date	(2)
- at Baring	3550	1959 - date(b)	(3)
- near Baileyville	3420	1919 - 1983	(4)
- at Spragues Falls	3500	1902 - 1905	(5)
Outlet of West Grand Lake:			
- at Grand Lake Stream	588	1928 - date	(6)
Dennis Stream:			
- at Moores Mills	62.2	1919 - 1920(d)	(7)
- near St. Stephen	115	1966 - date(d)	(8)
Chamcook Stream:			
- at Little Chamcook Lake Outlet	N/A	1968 - date(d)	(9)

WATER LEVEL

Station	Period of Record	
Grand Lake at Forest City	1915 - date	(10)
Spednic Lake at Vanceboro (St. Croix)	1915 - date	(11)
West Grand Lake at Grand Lake Stream	1915 - date	(12)
Grand Falls Lake (Flowage) at Grand Falls	1935 - date(c)	(13)
West Branch St. Croix River at Baileyville	1910 - 1912	(14)
Milltown (Plant) Reservoir at Milltown	1935 - date	(15)

(a) Identifies stations in Figure 4.1.
(b) Identifies intermittent records exist prior to 1959 and as far back as 1914.
(c) Identifies intermittent records exist prior to 1935 and as far back as 1915.
(d) Identifies natural flow records.
N/A Not available



ST. CROIX RIVER BASIN
PILOT PROJECT STUDY AREA

HYDROMETRIC STATIONS &
WATER LEVEL STATIONS

Legend

■ WATER LEVEL ONLY STATION

▲ DISCHARGE STATION

[1] NUMBERS IDENTIFY STATIONS IN TABLE 4.1

USA
CAN.
Monument Brook
NORTH LAKE
GRAND LAKE
[10]
FOREST CITY
[1]
CHIPUTNETICOOK LAKES
SPEDNIC LAKE
[11]
VANCEBORO
ST. CROIX
McADAM
[2]
MAINE
NEW BRUNSWICK
ST. CROIX RIVER
SYSLADOBSIS LAKE
WEST GRAND LAKE
Tomah Stream
Canoose River
GRAND FALLS FLOWAGE
[13]
[12]
BIG LAKE
[6]
Grand L. Stream
Musquash Stream
[14]
PRINCETON
[4]
KELLYLAND
Dennis Stream
[7]
ST. STEPHEN
[8]
CALAIS
MILLTOWN
WOODLAND
[5]
[15]
[3]
MILLTOWN
BARING
CLIFFORD LAKE
[9]
ST. ANDREWS
PASSAMAQUODDY BAY
Scale
mi 4 2 0 2 4 mi
km 5 0 5 km
QUEBEC
NEW BRUNSWICK
St. Croix River Basin
MAINE
SAINT JOHN
BANGOR
BAY OF FUNDY
NOVA SCOTIA
ATLANTIC OCEAN

Figure 4.1

St. Croix River Basin Hydrometric Stations-
Period of Record

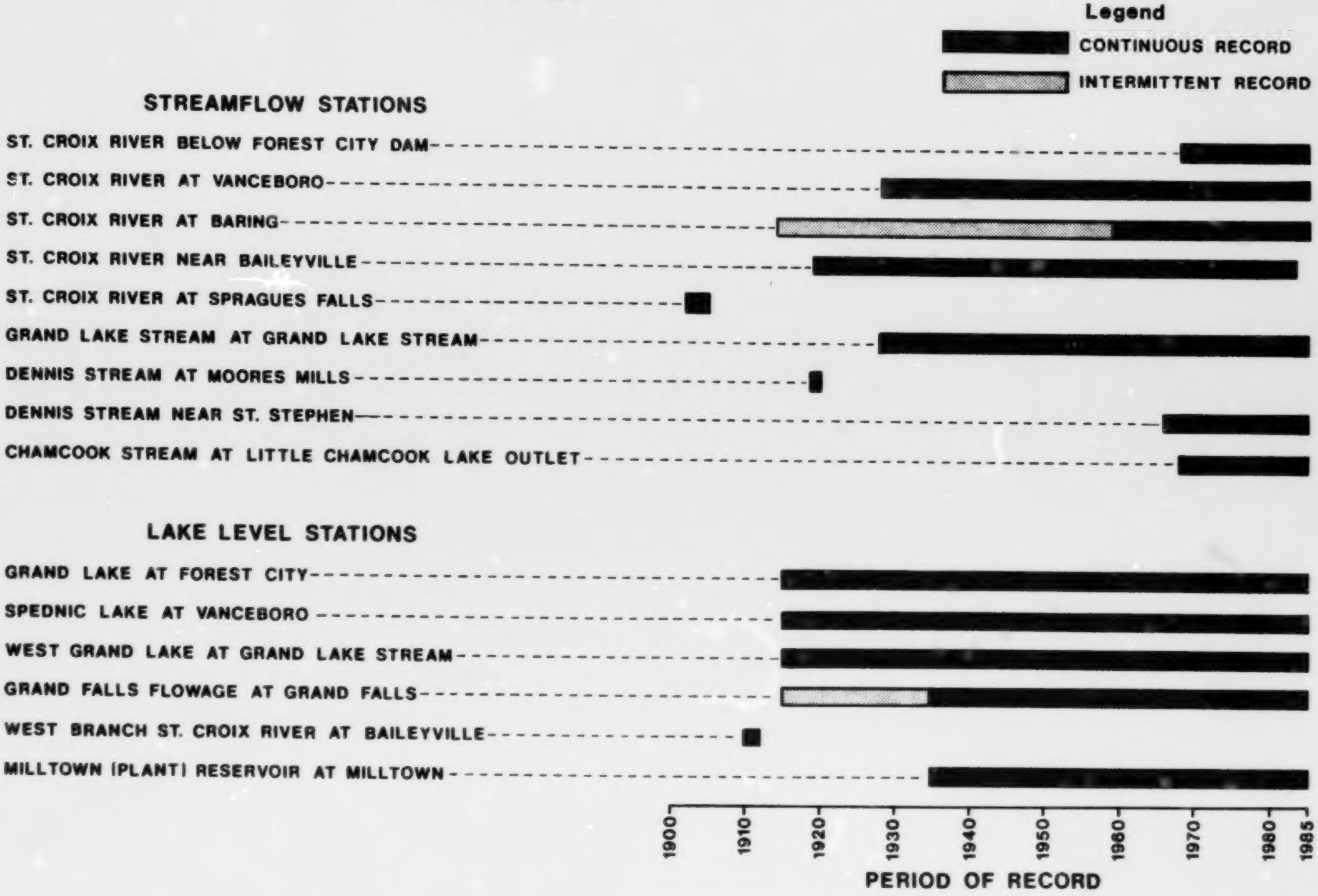


Figure 4.2

The United States Geological Survey maintained a water level gauge on the West Branch of the St. Croix River at Baileyville for a short period in the early nineteen hundreds.

A staff gauge at the Milltown Reservoir has been in operation since 1935. The gauge is maintained by The New Brunswick Electric Power Commission.

4.3.4 LAKE STORAGE DATA

The naturalization study was conducted for the four largest lakes in the basin because these are the only lakes for which regular records of stage are available in a quasi computerized data base. The four lakes (Grand, West Grand, Spednic and Grand Falls Flowage) contain about 91 percent of the total useable storage in the basin.

For the purpose of this project, it was necessary to select a base period for hydrologic analyses and the naturalization study. The period selected is from 1969 to 1985. This period was chosen as records of stage are available for the four major reservoirs, and records of streamflow at the four lake outflows are available in a computer data base format throughout the selected base period.

4.3.5 EVAPORATION DATA

Because of the large surface areas of some of the lakes in the basin, it was necessary to consider evaporation in the calculation of storage effects on streamflows. During the summer months, evaporation from some lakes is greater than the local inflow.

There are no records of evaporation in the St. Croix Basin. The nearest evaporation stations are at Caribou, Maine and Fredericton, New Brunswick. The United States Weather Bureau has recorded evaporation at Caribou since 1963, while the Atmospheric Environment Service, Department of the Environment, has records of evaporation from the Royal Road, IHD Station near Fredericton since 1966. There are no records of evaporation in the general area of the St. Croix River Basin prior to 1963.

Since the base period used in the study extends from 1969 to 1985, standard monthly values were used during the entire study period. While there are obvious errors in using average values because of climatic differences from year to year, this procedure is much more accurate than if evaporation were neglected completely. The monthly lake evaporation values are depicted in Figure 4.3.

4.3.6 STORAGE CAPACITY AND AREA RELATIONSHIPS

The stage-storage and stage-surface area relationships, for the four principle reservoirs, developed for use in this study are based on the estimates given in the Board of Control's 1975 report on the Spednic Lake Regulation Study.

A computer model utilizes a stage versus surface area relationship to compute evaporation losses as a function of lake surface area and calculates the monthly change in storage given the beginning and end of month lake surface elevations.

The area-capacity curves for the four reservoirs (Grand, Spednic, West Grand and Grand Falls) are presented in Figure 4.4.

4.4 PRELIMINARY ANALYSES OF HYDROMETRIC DATA

The mean annual runoff for the St. Croix River Basin, based on the Baileyville Hydrometric gauge for the period 1969 to 1985, is about 708 mm (27.9 inches) or 62 percent of the mean annual total precipitation for the same period. Flows in the St. Croix River are highly regulated by natural and man-made storages, however, winter storage of precipitation in the form of snow and ice cause more than one-third of the annual runoff to occur in the spring months of March, April, and May. Water levels of the largest reservoirs - Grand Lake (formerly East Grand Lake), Spednic Lake, West Grand Lake, and Grand Falls Flowage - have been regulated since 1914-1915. The Georgia-Pacific Corporation now operates the dams. A summary of the monthly flows and levels at selected locations is presented in Table 4.2

Information on high flows in the St. Croix River Basin is limited. Thanks to substantial natural storage areas and existing man-made lakes, normal spring freshets usually cause only limited damages. There have been no flooding problems of major importance in the basin in recent years. Flooding in the St. Croix River Basin is discussed in detail in the reference entitled "Flooding Events in New Brunswick, An Historical Perspective", revised March, 1985.

The available hydrometric data on flows for the entire period of record indicate that the St. Croix River has experienced a wide variation in magnitude of flows. The hydrometric station records at Baileyville and

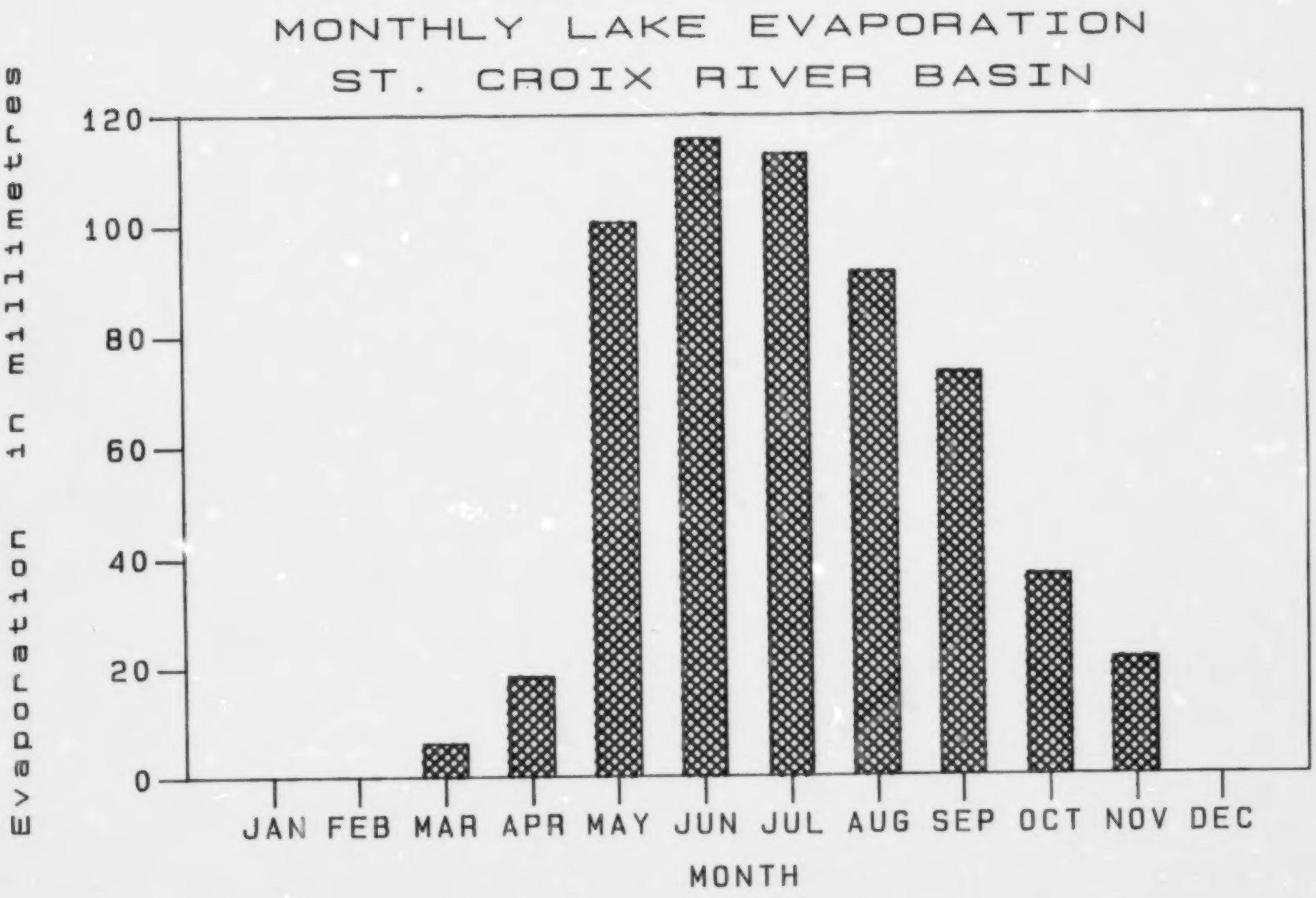
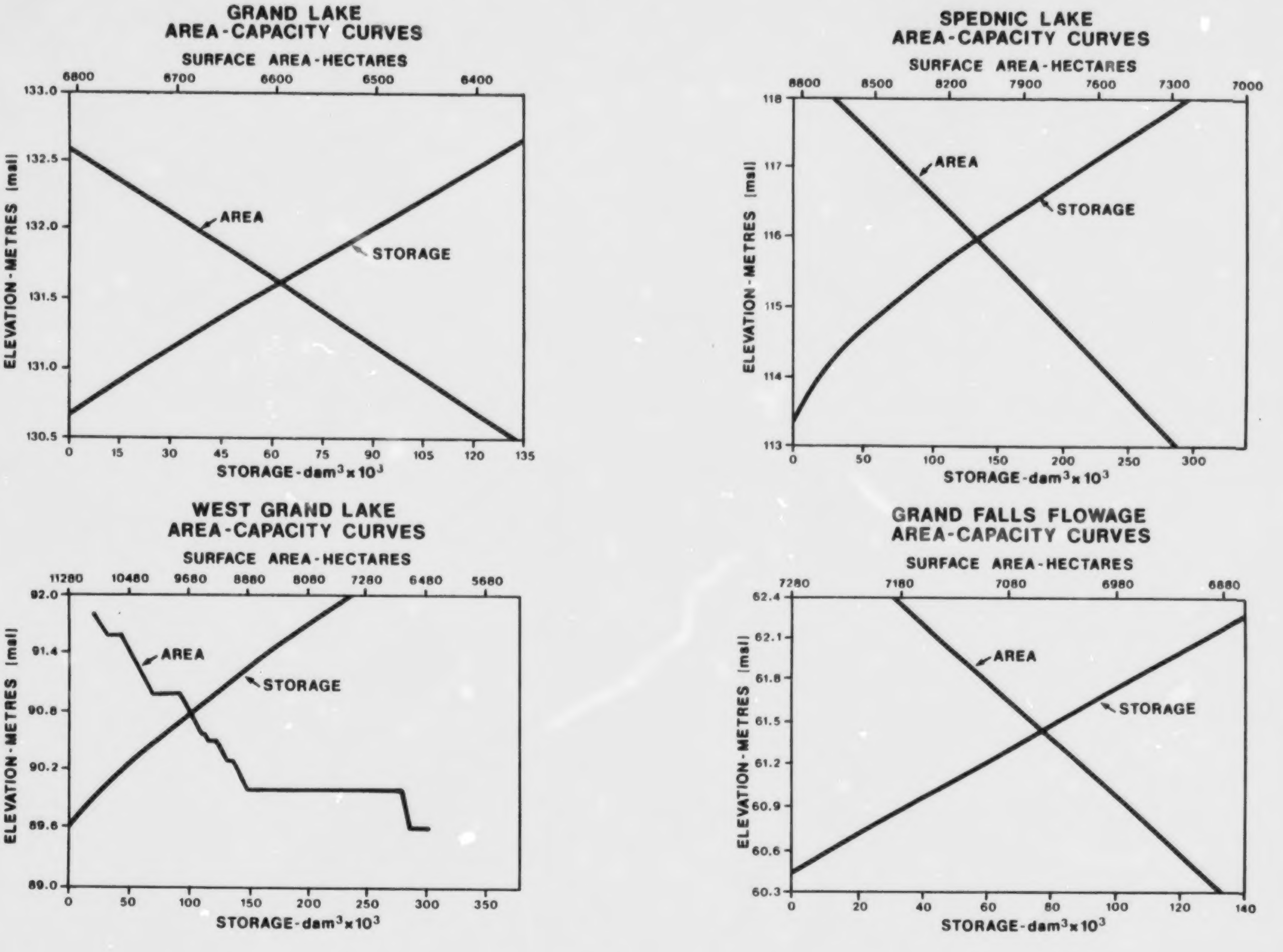

MONTHLY LAKE EVAPORATION
ST. CROIX RIVER BASIN
Evaporation in millimetres
120
100
80
60
40
20
0
JAN
FEB
MAR
APR
MAY
JUN
JUL
AUG
SEP
OCT
NOV
DEC
MONTH

Figure 4.3


GRAND LAKE AREA-CAPACITY CURVES

SPEDNIC LAKE AREA-CAPACITY CURVES

WEST GRAND LAKE AREA-CAPACITY CURVES

GRAND FALLS FLOWAGE AREA-CAPACITY CURVES

Figure 4.4

TABLE 4.2

DISCHARGE AND WATER LEVEL STATISTICS AT SELECTED LOCATIONS IN THE ST. CROIX RIVER BASIN

PERIOD 1969 TO 1985

Streamflow Stations	Maximum Monthly discharge (m^3/s)	Minimum Monthly discharge (m^3/s)	Mean Annual Runoff (mm)
St. Croix R. below Forest City Dam	21.5	2.15	620
St. Croix R. at Vanceboro	85.9	6.21	667
Grand Lake Stream at Grand Lake Stream	32.8	2.54	672
St. Croix R. near Baileyville	251	22.8	708
St. Croix R. at Baring	267	22.1	705
Dennis Stream near St. Stephen	12.9	0.024	796
Chamcook Stream at Little Chamcook Lake Outlet	0.866	0.003	Not Available

Lake Level Stations	Maximum Monthly Level (m)	Minimum Monthly Level (m)	Mean Annual Level (m)
Grand Lake	132.519	130.887	131.832
Spednic Lake	117.559	114.251	116.372
West Grand Lake	91.836	90.153	91.096
Grand Falls Flowage	62.076	60.503	61.791

Note:
1. Levels referred to mean sea level (metres).
2. St. Croix River at Baring period of record (monthly means time series) is from 1975 to 1985.
3. Periods with missing data, for example, St. Croix River near Baileyville, 1984 and 1985, were estimated.
4. Mean annual runoff in millimetres is calculated using the drainage area. There is no value for drainage area published for Chamcook Stream as it changes at high water.

at Baring give a good indication of the ranges that have occurred. The lowest daily flow of 1.81 m^3/s (63.9 cfs) was recorded at Baileyville on October 13, 1957, and the highest maximum instantaneous flow of 660 m^3/s (23,300 cfs) occurred on May 1, 1923. The Baileyville records extend from 1919 to 1983 and the mean daily discharge over this period was 66.8 m^3/s (2,360 cfs).

The Baring station was operated over a shorter period from 1959 to the present; this station is used to monitor flows in the St. Croix River below Woodland. Baring's lowest minimum daily discharge was 18.9 m^3/s (667 cfs) and occurred on August 18, 1978 with the highest maximum instantaneous discharge of 665 m^3/s (23,500 cfs) occurring on May 29, 1961. The mean daily discharge during the period 1975-85 was 79.3 m^3/s (2,800 cfs).

4.5 NATURALIZATION OF STREAMFLOW DATA

4.5.1 METHODOLOGY

Before statistical data interpretations of streamflow could be investigated, it was necessary to adjust the historical streamflow data for the influence of regulation. This was done using the mass balance equation relating inputs to and outputs from a lake to the change in storage in the lake.

The adjustments for the effect of past regulation were made by applying the following mass balance equation over monthly periods:

$$I_L = O + S + E - O_u$$

where:

I_L is the local inflow to the lake;

O is the recorded release from the lake;

S is the increase in storage in the lake;

E is the evaporation from the lake surface;

O_u is the recorded outflow from regulated lakes upstream;

(O_u is zero for Grand and West Grand Lakes).

Since information is available on O, S, E, and O_u, the local inflows can be computed for each month for each of the four major reservoirs in the basin. It should be pointed out that these local inflows are not, strictly speaking, natural outflows since they do not reflect the lake storage changes and lake evaporation which would have occurred under natural conditions, nor do they include the effect of artificial regulation of the smaller lakes in the basin for which storage data are not available. The local inflows are referred to as "natural" flows in this report to distinguish them from the recorded flow data.

The St. Croix reservoir system, as studied, includes the four major basin storages, i.e, the tandem Grand and Spednic Lakes on the East Branch in parallel with West Grand Lake on the West Branch, with the two branches flowing into Grand Falls Flowage on the main stem. Figure 4.5 presents a schematic of the main reservoirs: West Grand Lake, Grand Falls Flowage, Grand Lake and Spednic Lake.

Monthly discharges below the Forest City Dam were not recorded prior to 1975, thus for the years 1969 to 1974 inclusive, the monthly flows were computed indirectly based on the prorated data above the Vanceboro Dam. Also, monthly discharge records near Baileyville were discontinued after September 30, 1983. For the period October 1983 to December 1985 inclusive, the monthly flows were estimated using the records at Baring. These estimated flow values were needed to estimate the natural flow records at Grand, Spednic and Grand Falls Flowage.

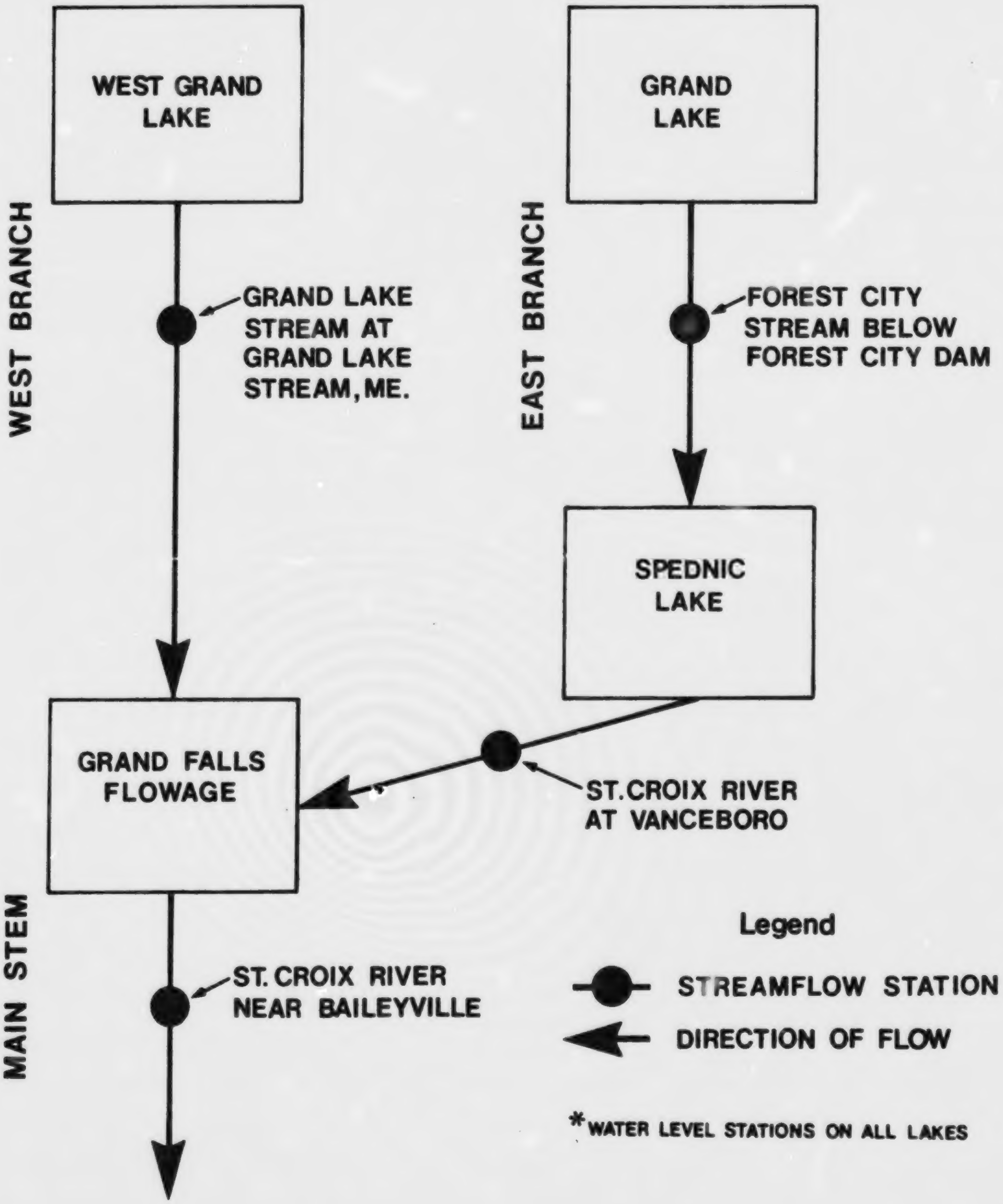
Natural outflows from the four principal storage areas were developed using monthly flow values for the period 1969 to 1985. In a few instances, the flows developed took on small negative values.

The negative values can be attributed to:

1) Natural errors such as wind inducing a seiche on the lake or channel on which a gauge is located,
2) Undetectable errors in the data transmitting process from actual reading to the final value input to the computer,
3) The inaccuracy of the approximated stage-storage curves for the major storages, and
4) Stage data for storages sometimes had to be interpolated over as long a period as two weeks.

To make the data acceptable for use in the naturalization analyses, the negative values had to be eliminated. This was done by arbitrarily adjusting the flows over a two or three month period in such a way that a negative value was eliminated without changing the total flow during the period. The magnitude of the adjustments are a very small part of the total annual flow and, therefore, these adjustments will have no appreciable effect on the results of the naturalization analyses.

SCHEMATIC OF ST. CROIX RIVER RESERVOIR SYSTEMS*


WEST GRAND LAKE
GRAND LAKE
WEST BRANCH
EAST BRANCH
GRAND LAKE STREAM AT GRAND LAKE STREAM, ME.
FOREST CITY STREAM BELOW FOREST CITY DAM
SPEDNIC LAKE
GRAND FALLS FLOWAGE
ST. CROIX RIVER AT VANCEBORO
MAIN STEM
ST. CROIX RIVER NEAR BAILEYVILLE
Legend
● STREAMFLOW STATION
← DIRECTION OF FLOW

*WATER LEVEL STATIONS ON ALL LAKES

Figure 4.5

4.5.2 PRESENTATION OF RESULTS

A comparison of "natural" and recorded outflows from each of the four principle reservoirs over the common period 1969-1985 is illustrated in Figure 4.6. These data are further presented in aggregate form in Figures 4.7 (Mean Monthly Runoff) and 4.8 (Annual Mean Runoff). Corresponding mean monthly and annual total precipitation are illustrated in Figures 4.9 and 4.10, respectively.

4.5.3 INTERPRETATION OF RESULTS

In general, the results are not particularily unexpected. The classical effects of regulation are clearly demonstrated. Extremes are moderated to a significant degree. However, the limitations of regulation are also obvious from the results. During extended periods of drought, flows are low under both "natural" and regulated conditions. However, even under extended periods of drought, regulated flows tend to be higher than under natural conditions. Had it been possible to simulate natural water levels, the results would have been even more dramatic.

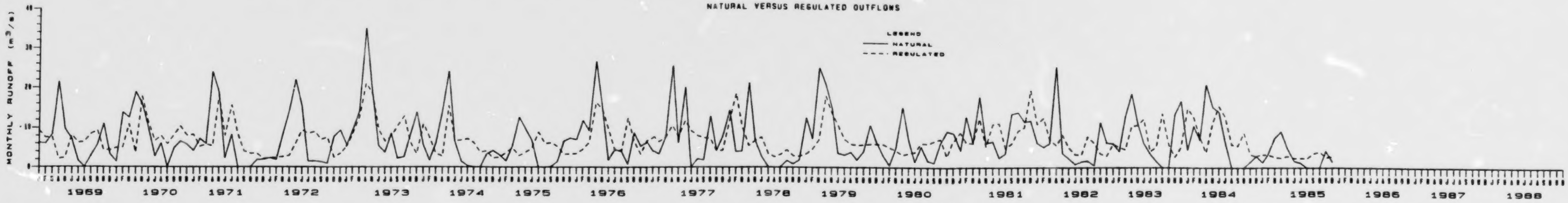
The views being voiced about the operation of the St. Croix River Basin concern excessive drawdowns in the reservoirs (mainly Spednic Lake) and the sudden changes in the rate of release from the dams (again mainly Spednic Lake). These problems are said to diminish the bass fishery, cause extensive foreshore exposure, cause loss of fish habitat, expose rocks which are hazardous to boating and snowmobiling and create low groundwater levels affecting shallow wells in the area.

During the last seventeen years, 1969-85, there has been a number of years (1971, 1974, 1975, 1978, 1985) when normal precipitation was not available to sustain required flows and it was necessary to draw more on storage reserve then usual. The years 1971 and 1985 were particularly dry years. The resulting effects in each case have been low water levels and complaints from cottage owners, fisherman, recreation/ tourism and fishing organizations.

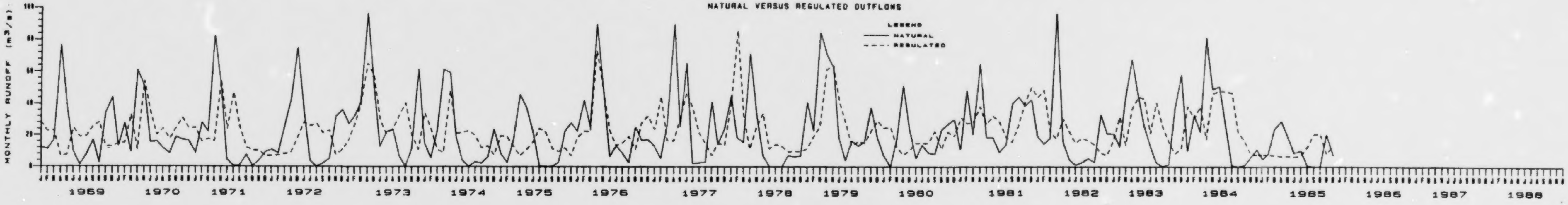
The report entitled, "Preliminary Report on the Status of Spednic Lake Regulation" (1986), summarizes the St. Croix River salmon restoration as follows: "The anadromous fishery restoration, which is well underway,

> has been relatively successful. Atlantic salmon have been reintroduced to the river and fish counts have shown that each year brings these prized game fish in larger numbers back from the ocean."

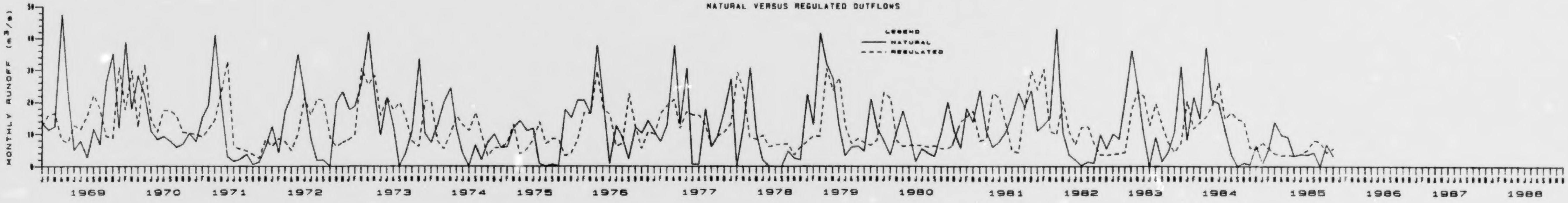
COMPARISON OF MONTHLY RUNOFFS
GRAND LAKE
NATURAL VERSUS REGULATED OUTFLOWS



COMPARISON OF MONTHLY RUNOFFS
SPEDNIC LAKE
NATURAL VERSUS REGULATED OUTFLOWS



COMPARISON OF MONTHLY RUNOFFS
WEST GRAND LAKE
NATURAL VERSUS REGULATED OUTFLOWS



COMPARISON OF MONTHLY RUNOFFS
GRAND FALLS FLOWAGE
NATURAL VERSUS REGULATED OUTFLOWS

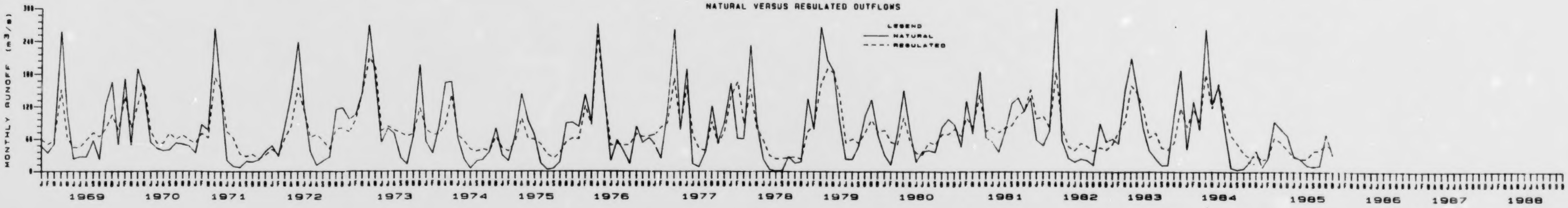


Figure 4.6

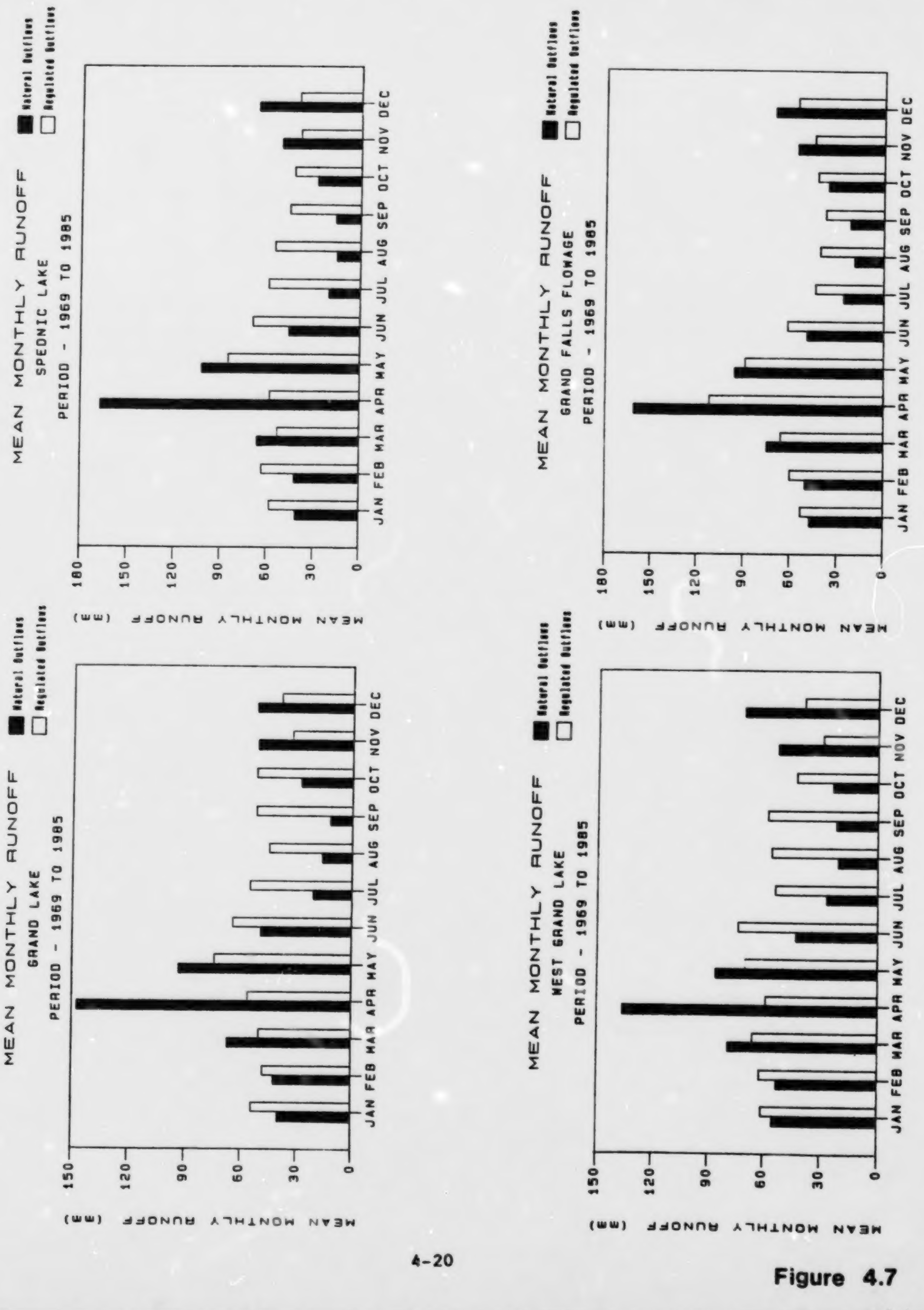

MEAN MONTHLY RUNOFF
SPEDNIC LAKE
PERIOD - 1969 TO 1985
Natural Outflows
Regulated Outflows
MEAN MONTHLY RUNOFF (mm)
180
150
120
90
60
30
0
JAN FEB MAR APR MAY JUN JUL AUG SEP OCT NOV DEC
MEAN MONTHLY RUNOFF
GRAND LAKE
PERIOD - 1969 TO 1985
Natural Outflows
Regulated Outflows
MEAN MONTHLY RUNOFF (mm)
150
120
90
60
30
0
JAN FEB MAR APR MAY JUN JUL AUG SEP OCT NOV DEC
MEAN MONTHLY RUNOFF
GRAND FALLS FLOWAGE
PERIOD - 1969 TO 1985
Natural Outflows
Regulated Outflows
MEAN MONTHLY RUNOFF (mm)
180
150
120
90
60
30
0
JAN FEB MAR APR MAY JUN JUL AUG SEP OCT NOV DEC
MEAN MONTHLY RUNOFF
WEST GRAND LAKE
PERIOD - 1969 TO 1985
Natural Outflows
Regulated Outflows
MEAN MONTHLY RUNOFF (mm)
150
120
90
60
30
0
JAN FEB MAR APR MAY JUN JUL AUG SEP OCT NOV DEC

Figure 4.7

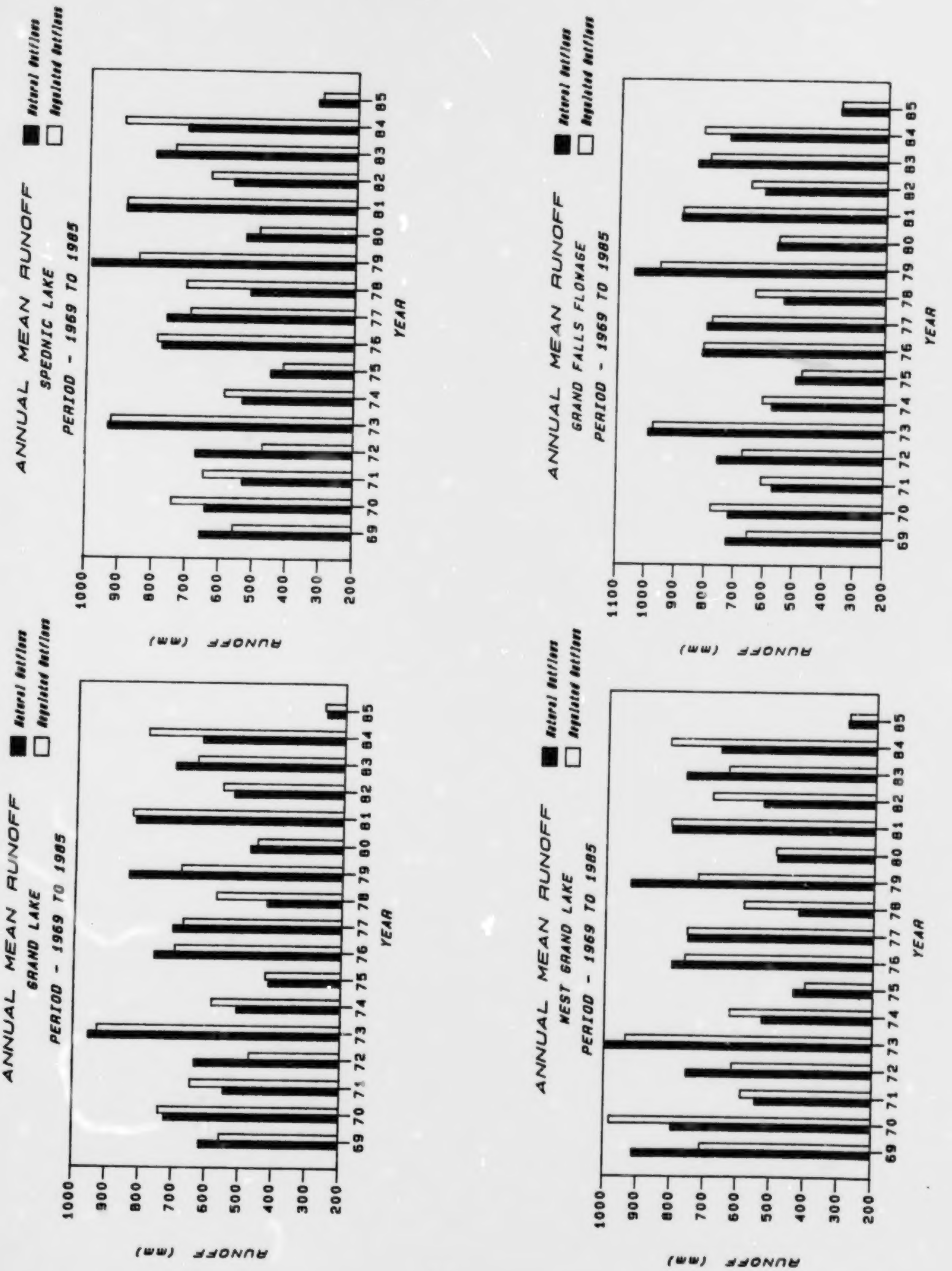
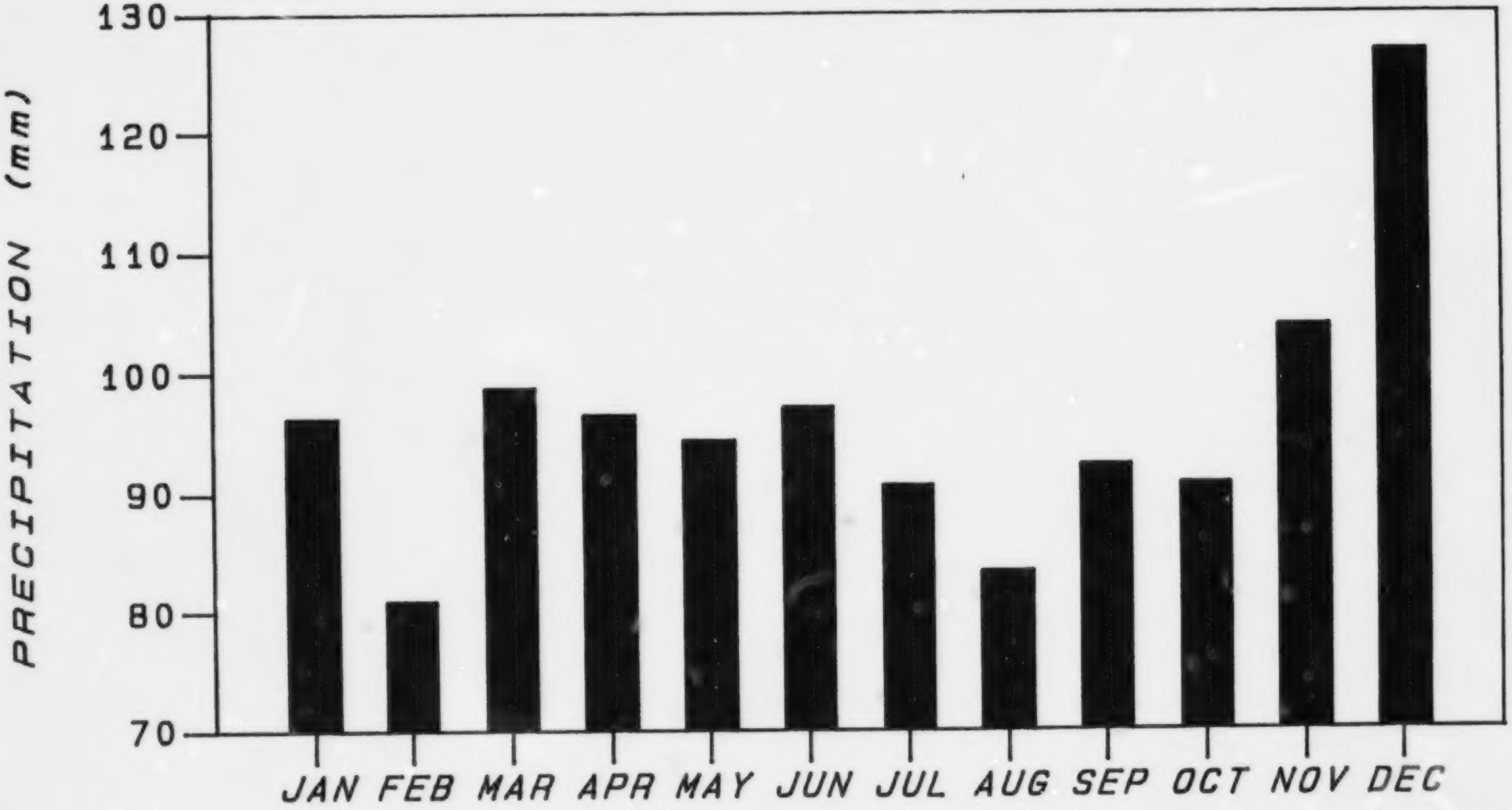

ANNUAL MEAN RUNOFF
SPEDNIC LAKE
PERIOD - 1969 TO 1985
Natural Outflows
Regulated Outflows
RUNOFF (mm)
YEAR
1000
900
800
700
600
500
400
300
200
69 70 71 72 73 74 75 76 77 78 79 80 81 82 83 84 85
ANNUAL MEAN RUNOFF
GRAND LAKE
PERIOD - 1969 TO 1985
Natural Outflows
Regulated Outflows
RUNOFF (mm)
YEAR
1000
900
800
700
600
500
400
300
200
69 70 71 72 73 74 75 76 77 78 79 80 81 82 83 84 85
ANNUAL MEAN RUNOFF
GRAND FALLS FLOWAGE
PERIOD - 1969 TO 1985
Natural Outflows
Regulated Outflows
RUNOFF (mm)
YEAR
1100
1000
900
800
700
600
500
400
300
200
69 70 71 72 73 74 75 76 77 78 79 80 81 82 83 84 85
ANNUAL MEAN RUNOFF
WEST GRAND LAKE
PERIOD - 1969 TO 1985
Natural Outflows
Regulated Outflows
RUNOFF (mm)
YEAR
1000
900
800
700
600
500
400
300
200
69 70 71 72 73 74 75 76 77 78 79 80 81 82 83 84 85

Figure 4.8

MEAN MONTHLY TOTAL PRECIPITATION
ST. CROIX RIVER BASIN
PERIOD - 1969 TO 1985



Based on Canterbury, NB. Vanceboro & Woodland, Me

Figure 4.9

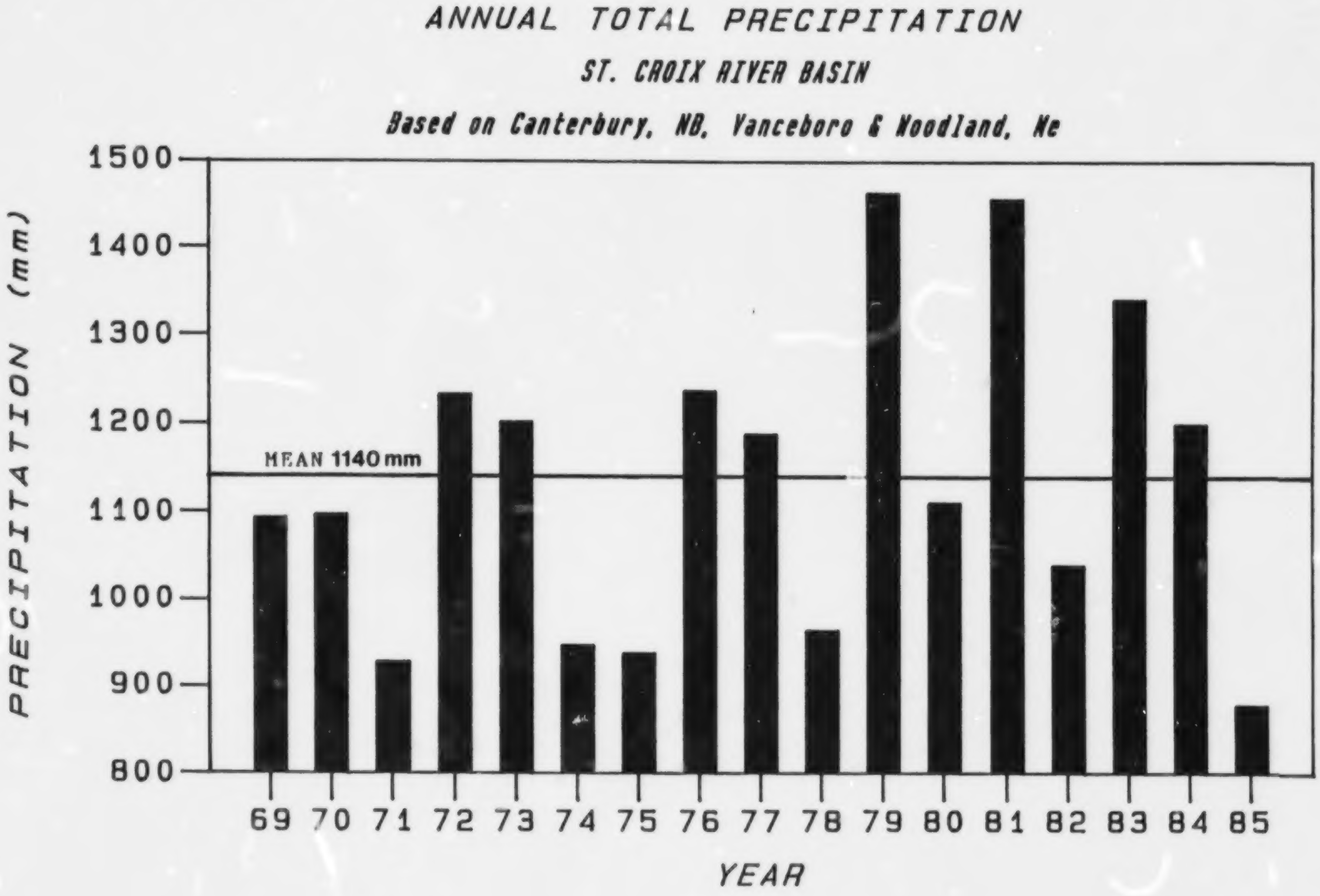

ANNUAL TOTAL PRECIPITATION
ST. CROIX RIVER BASIN
Based on Canterbury, NB, Vanceboro & Woodland, Me
PRECIPITATION (mm)
1500
1400
1300
1200
1100
1000
900
800
MEAN 1140 mm
69
70
71
72
73
74
75
76
77
78
79
80
81
82
83
84
85
YEAR

Figure 4.10

Restoration advocates claim that these anadromous runs would be even more successful if the flows were higher than the required current minimum control flow of 21.2 m^3/s (750 cfs) as measured at the Baring, Maine gauge. Also, the Maine D.E.P. (Mitnik, 1986) has pointed out that this flow is a mean daily discharge and not an instantaneous requirement. The D.E.P. is recommending that the minimum flow requirement be instantaneous rather than a 24 hour mean flow in order to protect against any future fish kills. The section on surface water quality describes a 1980 fish kill incident which supports this approach. Furthermore, the Maine D.E.P. is recommending a flow of 27.5 m^3/s (970 cfs) during the summer months (June 1 to September 30), and 21.2 m^3/s (750 cfs) during the remainder of the year. Figure 4.9 above illustrates that precipitation is at its lowest (summer months) during August and that the regulated outflows draw upon more lake storage precisely during the period when the higher flow is recommended.

The current minimum maintenance flow of 21.2 m^3/s (750 cfs) is a large factor in producing the upstream, lake level drawdowns being experienced during periods of deficient rainfall. Larger downstream flows could exacerbate the drawdown problem on Spednic Lake, expecially if the flows were to be augmented mainly from Spednic Lake. In periods of prolonged deficient rainfall, such as the sixteen-month period of July 1984 through October 1985, natural rainfall runoff which provides lake inflows becomes negligible and virtually all lake outflows come from storage. This in fact is the reason that regulation/storage is established in the first place, so that flows that would exist in the St. Croix River under "natural" conditions, can be increased with water from storage in the lakes. It has been demonstrated that flows during droughts under natural conditions would be more severe than those that actually occurred. Conversely, demands by residents along Spednic Lake for increased water levels during the summer months would have the effect of lowering downstream flows and hydroelectric generation.

If flows were substantially reduced due to drought conditions, or if flows were not augmented from storage, it is evident that dissolved oxygen levels could be reduced below the objective level of 5 mg/l. The 1980 fish kill amply illustrates this premise.

The regulated lakes (reservoirs) in the St. Croix River Basin are operated by G-P for the production of hydroelectric power at the Grand

Falls Dam at Kellyland and at the mill in Woodland, Maine. The operations of these lakes are subject to control regulations (see Section 4.2 above) which specify minimum maintenance flows, and maximum/minimum water levels for pollution abatement, for protection of fish life and for recreational activities. Note that some of the control regulations are required by the I.J.C. and E.P.A., whereas some are "desired", and "desired flows" are defined as those that would be the maximum constant streamflow if regulation capacity was unlimited. The maximum desired flow is therefore equal to the long-term mean annual flow. The desired flow or mean annual flow at Woodland is 65.1 m^3/s (2300 cfs), and the reservoir system rule curve was developed on the basis of this flow. In years of lower precipitation than normal, this rule is obviously problematic.

Reservoir storage zones were designated as the following: dead storage; buffer storage; conservation storage; and flood control storage. Releases from the conservation zone generally provide "desired flows", while the buffer is reserved to meet "required flows" in the event conservation storage is exhausted. Water in the dead storage zone is unavailable for release, while water in the flood control zone would be above the desired levels and would be released as rapidly as possible without exceeding downstream channel capacity.

The operation of the four reservoirs is essentially the same, i.e. water is stored during the snowmelt months (March, April, May) and released during the summer and fall. In general, during the late fall early winter (November and December) water is held in storage. As presented in Figure 4.9, November and December are the wettest months. The distribution of the regulated outflows is less variable, throughout the year, than the natural runoff. In other words, low runoff periods are augmented whereas the magnitude of the spring freshets are alleviated.

A very delicate and complicated balancing situation exists in this basin. To satisfy all of the conflicting users is clearly an impossible task as the total quantity of water available may be insufficient to satisfy flow requirements and maintain lake levels.

Surface water hydrology is an important aspect in the St. Croix River Basin as it has a direct influence on flow regulation and the capability of the watershed to yield minimum flow requirements.

This section illustrates that regulation results, in general, in mitigation of flow extremes and also provides an improved control of lake elevations.

Other flow requirements for tourism and recreational purposes are currently unknown, although G-P reports that canoeists desire 12.7 m^3/s (450 cfs), or higher, be released from Vanceboro.

SECTION FIVE
SURFACE WATER QUALITY

5.0 SURFACE WATER QUALITY

5.1 OVERVIEW OF FACTORS INFLUENCING PRESENT AND PAST WATER QUALITY

Water quality in the St. Croix River reflects the surficial geology and the human influences within the confines of the drainage basin. The upper reach of the river is relatively free of human influences, and is considered to represent natural or background conditions.

The surficial geology of the St. Croix River Basin is such that precipitation reaches the river channel without much delay. Under natural flow conditions, the rain and snowmelt can dissolve only small amounts of the soil minerals. River water in the upper reaches of the basin is therefore low in dissolved solids but is coloured by drainage from the bogs which are scattered along the tributaries.

Until establishment of the pulp and paper operation at Woodland, Maine, the quality of the water which entered Passamaquoddy Bay changed very little over its 124 km run from Monument Brook to the sea. With the rise of the pulp and paper industry, industrial effluent was introduced to the river at Woodland so that the quality of water in the lower 14 km of the river deteriorated to a state where anadromous fish could no longer survive passage through this portion. Other factors contributing to the deterioration of water quality included the additon of domestic and municipal sewage from the communities and cottages situated on the lower reaches of the St. Croix. Fecal coliform counts in the estuary at Oak Bay, even yet, prevent the harvest of shellfish for human consumption, and prevents the use of fresh river water for domestic consumption.

Very recent history, however, shows that the situation with water quality below Woodland is improving. Changes in mill process and treatment of the effluent has ameliorated the condition of the receiving water below the mixing zone to the extent that Atlantic salmon can now pass up the river to reproduce in the upper reaches.

Available water quality data for the river from 1965 to the present will be reviewed and related to changes in mill processes and effluent treatment that have occurred during that time period. In addition, water quality objectives and guidelines will be considered as targets for the improvement of water quality for the possible propagation of fish throughout the entire length of the river.

5.2 OVERVIEW OF WATER QUALITY GUIDELINES AND OBJECTIVES

It is important to realize the distinction between water quality guidelines and objectives. The "Canadian Water Quality Guidelines" (CCREM, 1987) defines water quality terms as follows:

1. Criteria: scientific data evaluated to derive the recommended limits for water uses.

2. Water quality guideline: numerical concentration or narrative statement recommended to support and maintain a designated water use.

3. Water quality objective: a numerical concentration or narrative statement which has been established to support and protect the designated uses of water at a specified site.

4. Water quality standard: an objective that is recognized in enforceable environmental control laws of a level of government.

Water quality guidelines applicable to the St. Croix River are: raw water for drinking water supply; recreational water quality and aesthetics; and freshwater aquatic life. Guidelines for the protection of freshwater aquatic life are considered to be the most stringent for present uses of the river, and because of the obvious need and desire to protect the biota of the river. It should, however, be noted that there are additional data available that are not considered under the guidelines for the protection of freshwater aquatic life. An examination of these additional data in comparison to guidelines for raw water for drinking water supply and for recreational water quality and aesthetics will be of assistance to other water users, in particular for recreational activities.

Water quality objectives, on the other hand, are more specific than guidelines in that they apply to individual bodies of water. Often objectives are associated with a goal which is specific to the body of water.

For the St. Croix River, water quality objectives with particular reference to salmon passage were proposed by the IJC's Pollution Advisory Control Board (PACB). To date, objectives for dissolved oxygen and pH have been established (5.0 mg/l and 60%. saturation, and 6.0 to 8.5 pH units respectively).

By 1978, improvements in the water quality of the lower 14 km stretch of the river made possible the passage of Atlantic Salmon (Salmo salar), and in 1980, a program for the re-introduction of Atlantic salmon was commenced.

The public health safety standard for shellfish and shellfish harvesting waters in Canada is judged presently by bacteriological standards. These standards require that the "most probable numbers (MPN) of fecal coliforms in water not exceed a median of 14 per 100 ml and that no more than 10% of the samples exceed 43 fecal coliforms per 100 ml in areas approved for the harvesting of shellfish". The foregoing limits need not be applied if it can be shown by detailed study that the fecal coliforms are not of direct fecal origin and/or sanitary surveys do not indicate a public hazard (Menon et al, 1982).

The presence of fecal coliform also precludes the use of river water for domestic consumption since water quality guidelines indicate that water consumed should contain no fecal coliform for domestic consumption. The water quality guidelines for the protection of freshwater aquatic life and objectives are presented in Table 5.1.

TABLE 5.1

SELECTED WATER QUALITY GUIDELINES AND OBJECTIVES FOR PROTECTION OF FRESHWATER AQUATIC LIFE

PARAMETER	OBJECTIVES	DETECTION	GUIDELINES* FOR PROTECTION OF FRESHWATER AQUATIC LIFE
Dissolved Oxygen	5.0 mg/l 60% sat.	0.5 mg/l	5.0 mg/l
pH	6.0 - 8.5 units		
Aluminum, as total Al		0.01 mg/l	<0.100 mg/l
Cadmium, as total Cd		0.001 mg/l	<0.0002 mg/l
Copper, as total Cu		0.002 mg/l	<0.005 mg/l
Iron, as total Fe		0.05 mg/l	<0.300 mg/l
Lead, as total Pb		0.002 mg/l	<0.03 mg/l
Mercury, as total Hg		0.02 mg/l	<0.100 mg/l
Suspended Solids		10 mg/l	<10 mg/l

* CCREM, 1987

5.3 WATER QUALITY SAMPLING

Water quality data for the St. Croix River are available from 1952. At that time, the Canadian Department of National Health and

Welfare (N.H.W.) began sampling at Kellyland. In 1954, two additional stations at St. Croix and Milltown were included in the N.H.W. program.

On July 23, 1965, water quality sampling of the St. Croix by what is now the Water Quality Branch of Environment Canada was started and, since that time, sampling has continued at various sites (Table 5.2, Figures 5.1 and 5.2).

Since 1980, WQB has monitored physical parameters, major ions, heavy metals and nutrients at an approximate frequency of 8 times a year. Results provide information on the long term impact of pulp mill waste, and assist the PACB who has the responsibility for water quality monitoring and co-ordination of water quality planning activities in the St. Croix River Basin.

In 1986, three additional sampling sites, Grand Lake Outlet at Forest City, Diggity Stream, and St. Croix River at St. Croix were added to the 3 regular monitoring sites currently in use. These sites were added to enhance comparisons of present water quality conditions above and below the Georgia-Pacific Mill at Woodland, Maine. Historical data exists for two of these stations while one (Diggity Stream) was sampled for the first time. Sampling was carried out three times in 1986 at the three additional stations.

In addition to conducting systematic grab sampling of river water, the WQB in Moncton has been receiving, since June 1985, data via satellite retransmission, on a real time basis, from an automatic water quality monitor (AWQM) owned and operated by United States Geological Survey (USGS). The AWQM was installed in September 1969 at Milltown Heights and is co-located with WQB's sampling station at Milltown. The AWQM continually measures pH, specific conductance, temperature and dissolved oxygen.

The hourly data from the AWQM at Milltown are obtained in Moncton using a Labarge GOES satellite data collection platform, and stored in the Water Quality Branch minicomputer. The raw data are then edited on a monthly basis and graphical displays of daily minimum, maximum and median values of the hourly data are constructed. Graphical summaries of the hourly data are considered provisional and are included in a yearly report to the PACB for the St. Croix River.

In addition, the USGS is responsible for final editing and archiving of data resulting from the Milltown AWQM, and publishes yearly

TABLE 5.2

NAQUADAT NUMBERS AND SITE DESCRIPTIONS OF ALL SAMPLING STATIONS ON THE ST. CROIX RIVER

NAQUADAT	Location Identifier(a)	Station Location
OONBO1ARO011	A*	Grand Lake outlet at Hwy Bridge, Forest City
OONBO1ARO029	B*	Diggity Stream Outflow from First to Spednic Lake at Hwy
OONBO1ARO002	C*	St. Croix River at St. Croix Bridge, Canadian side
OONBO1ARO013	D*	St. Croix River at Kellyland
OONBO1ARO014	E*	St. Croix River, 200 m below Woodland Mill on the U.S. side of the river
OONBO1ARO017	F	St. Croix River at Baring RR Bridge - U.S. side
OONBO1ARO018	G	St. Croix River at Baring RR Bridge - Mid river
OONBO1ARO019	H	St. Croix River at Baring RR Bridge - Canadian side
OONBO1ARO020	I+	St. Croix River at Milltown Hwy Bridge - U.S. side
OONBO1ARO001	J*	St. Croix River at Milltown Hwy Bridge - Mid-river
OONBO1ARO021	K	St. Croix River at Milltown Hwy Bridge - Canadian side

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* 1986 Sampling Stations

+ Also location of USGS AWQM

(a) Identifies station locations on Figure 5.2

Period of Record-St. Croix River Water Quality Sampling Stations
(On Naquadat by Various Agencies)

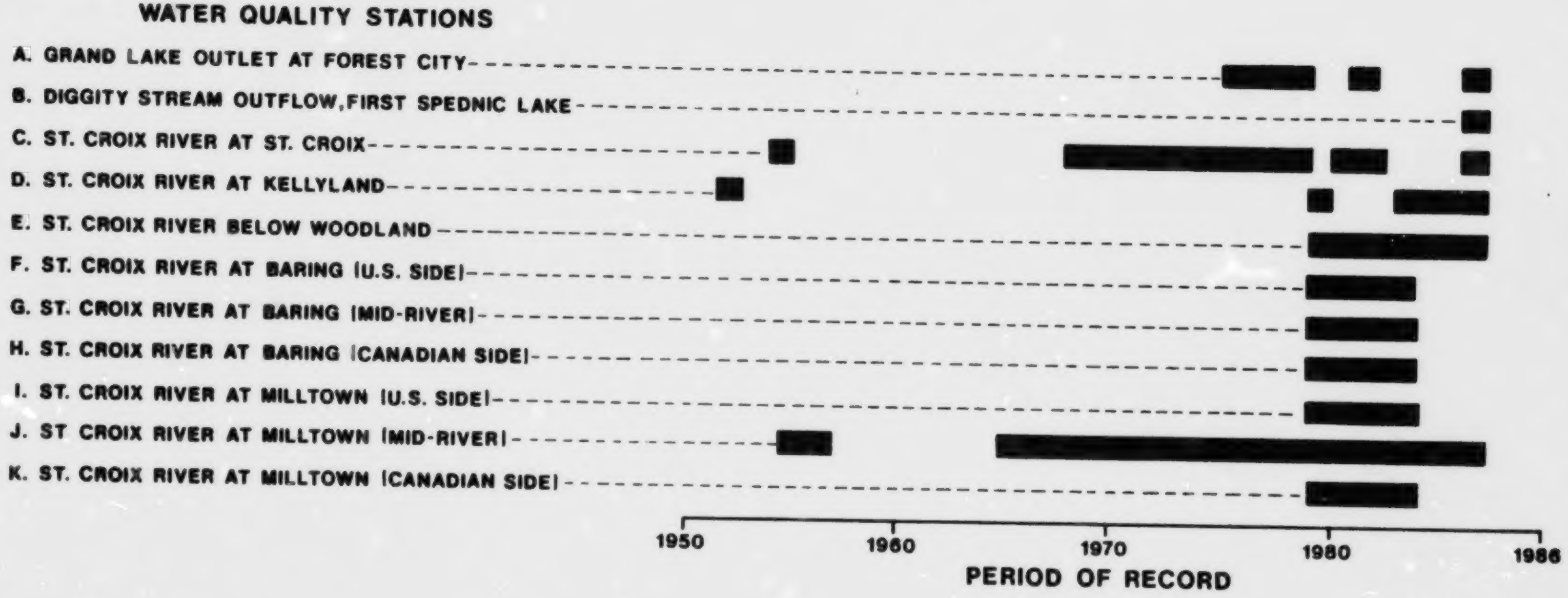
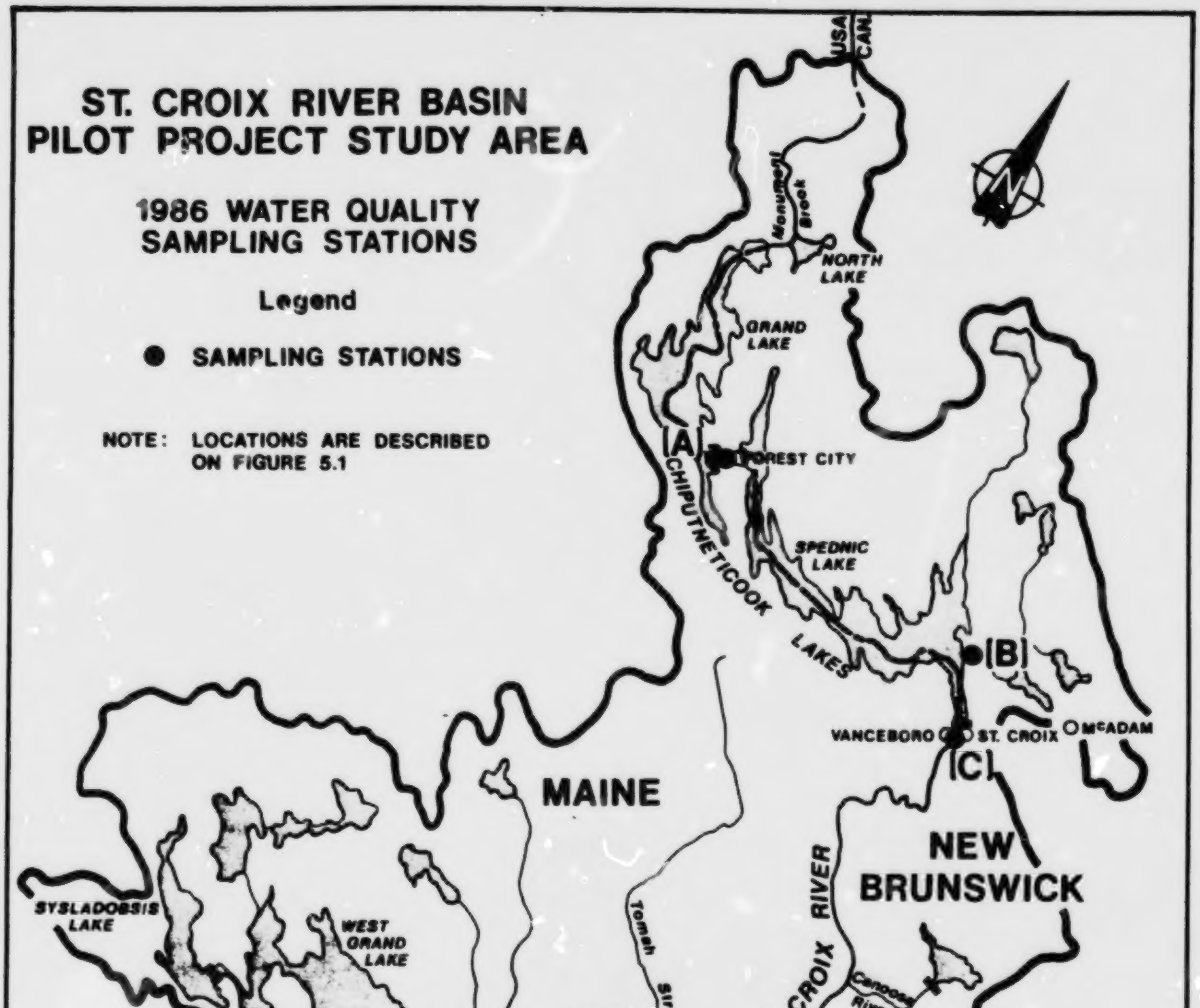


Figure 5.1



ST. CROIX RIVER BASIN
PILOT PROJECT STUDY AREA

1986 WATER QUALITY
SAMPLING STATIONS

Legend

● SAMPLING STATIONS

NOTE: LOCATIONS ARE DESCRIBED
ON FIGURE 5.1

USA
CAN
Monument Brook
NORTH LAKE
GRAND LAKE
[A]
FOREST CITY
CHIPUTNETICOOK LAKES
SPEDNIC LAKE
[B]
VANCEBORO
ST. CROIX
McADAM
[C]
MAINE
NEW BRUNSWICK
SYSLADOBSIS LAKE
WEST GRAND LAKE
BIG LAKE
Grand L. Stream
Musquash Stream
GRAND FALLS FLOWAGE
Tomah Stream
ST. CROIX RIVER
Canoose River
KELLYLAND
PRINCETON
[D]
Dennis Stream
ST. STEPHEN
MILLTOWN
WOODLAND
CALAIS
[J]
[E]
U.S.G.S. AUTO-MONITER
BARING
QUEBEC
NEW BRUNSWICK
St.Croix River Basin
SAINT JOHN
MAINE
BANGOR
BAY OF FUNDY
NOVA SCOTIA
ATLANTIC OCEAN
Scale
mi 4 2 0 2 4 mi
km 5 0 5 km

Figure 5.2

summaries of raw data (daily minimum, maximum and means) for all of the parameters measured on a water year basis (October to September) in their publication "Water Resources Data, Maine, Water Year ...", U.S. Geological Survey Water-Data Report Series.

5.4 VARIATIONS IN WATER QUALITY

5.4.1 HISTORICAL CHANGES IN WATER QUALITY

The St. Croix River did not always experience water quality problems. Davis (1974) indicates that the St. Croix River was being used directly as community drinking water for St. Stephen from 1886 until pulp mill operations commenced in 1906. It was a result of river water quality degradation that the present water source was developed. Water quality was not quantified, however, until more recent years.

Data for the various parameters tested are presented in the form of box and whisker plot format as described in Figure 5.3. Data for sulphate, magnesium, sodium, calcium, chloride, total alkalinity and specific conductance are available for the period from 1965 to 1986. These data indicate that only one or two samples were collected in the years 1977, 1980, 1981 and 1982 for the St. Croix River at St. Croix station, and therefore are omitted from the plots.

The box and whisker plots for St. Croix River at St.Croix, which represents the river water quality above Woodland, (Figures 5.4 to 5.9) indicates that water quality parameters measured have been very stable over time, but temporal changes at Milltown, which represents the river water quality below Milltown, (Figures 5.10 to 5.16) are more pronounced for such parameters as sodium, sulphate, calcium, magnesium, total alkalinity and chloride. These parameters reflect the changes in mill process and treatment at the G.-P. mill. Table 5.3 provides a summary of how mill processes have changed over time and the resulting effluent has undergone improved treatment over time.

For example, prior to 1966, the mill employed a sulphite process and the water chemistry at Milltown was characterized by high sulphate (Figure 5.10) and magnesium (Figure 5.11) concentrations. A shift to the Kraft processes in 1966 resulted in a decrease of sulphate and magnesium, and increases in sodium (Figure 5.12), chloride (Figure 5.13), calcium (Figure 5.14), and total alkalinity (Figure 5.15). From 1966 to

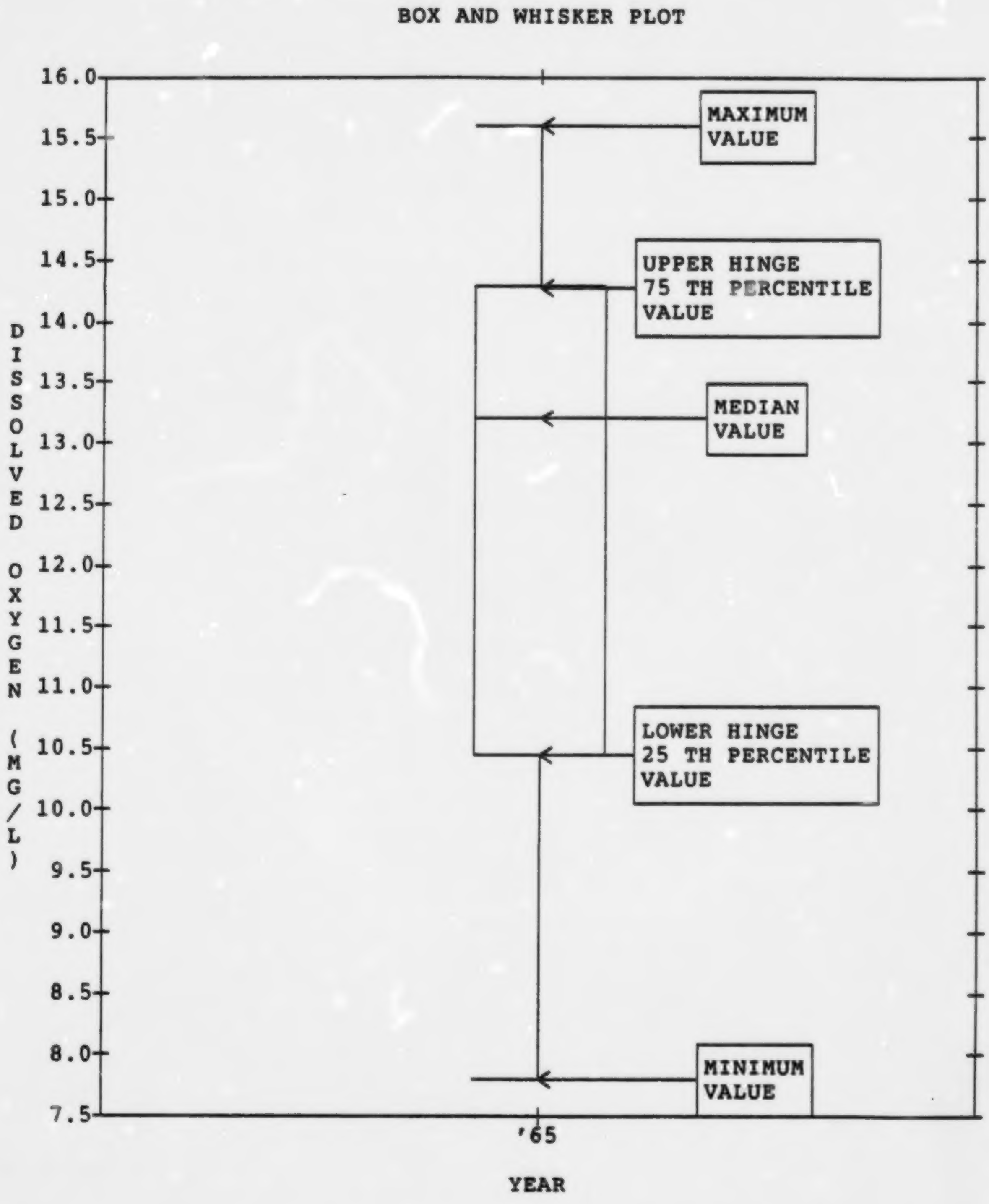

BOX AND WHISKER PLOT
16.0
15.5
15.0
14.5
14.0
13.5
13.0
12.5
12.0
11.5
11.0
10.5
10.0
9.5
9.0
8.5
8.0
7.5
DISSOLVED OXYGEN (MG/L)
MAXIMUM VALUE
UPPER HINGE 75 TH PERCENTILE VALUE
MEDIAN VALUE
LOWER HINGE 25 TH PERCENTILE VALUE
MINIMUM VALUE
'65
YEAR

Figure 5.3

Figure 5.4
SULFATE (MG/L) IN ST CROIX RIVER AT ST CROIX
DATA FROM WQB GRAB SAMPLES

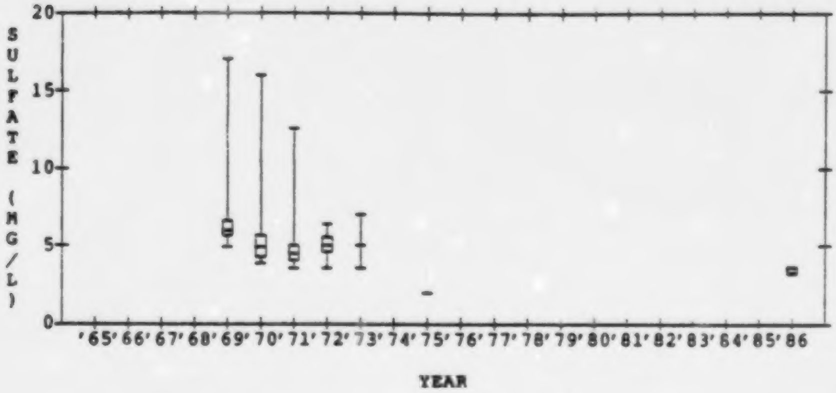


Figure 5.5
MAGNESIUM (MG/L) IN ST CROIX RIVER AT ST CROIX
DATA FROM WQB GRAB SAMPLES

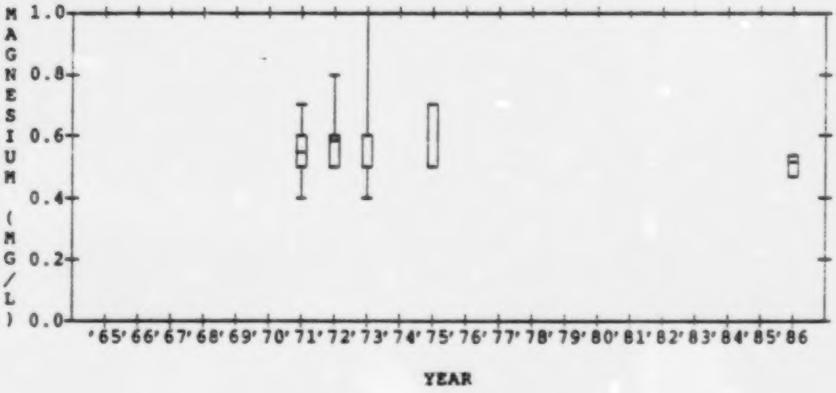


Figure 5.6
SODIUM (MG/L) IN ST CROIX RIVER AT ST CROIX
DATA FROM WQB GRAB SAMPLES

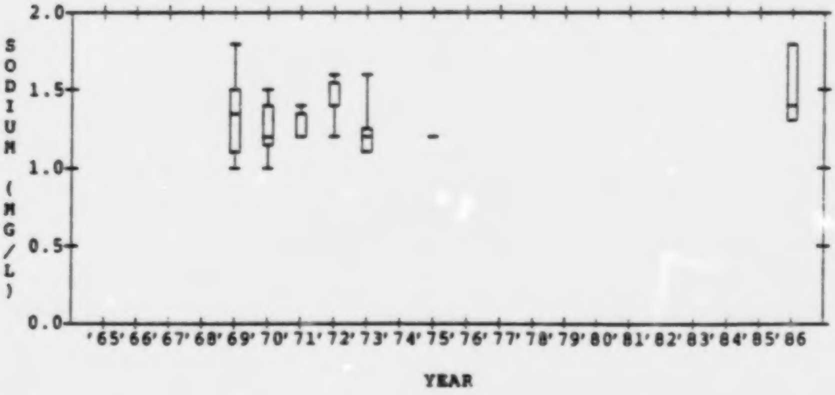


Figure 5.7

CALCIUM (MG/L) IN ST CROIX RIVER AT ST CROIX
DATA FROM WQB GRAB SAMPLES

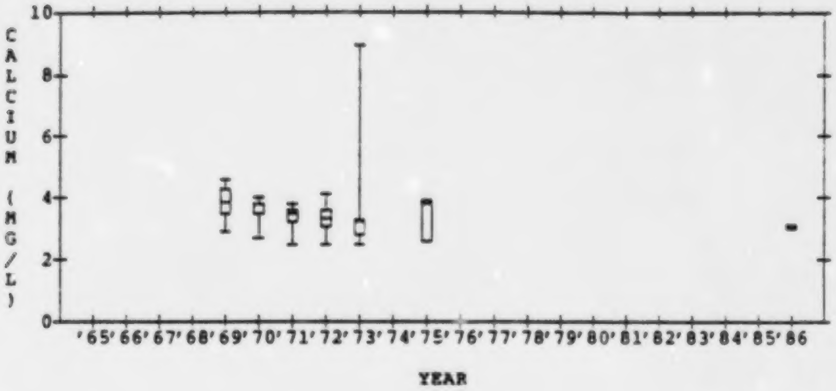


Figure 5.8

TOTAL AKLALINITY (MG/L AS CaCO3) IN ST CROIX RIVER AT ST CROIX
DATA FROM WQB GRAB SAMPLES

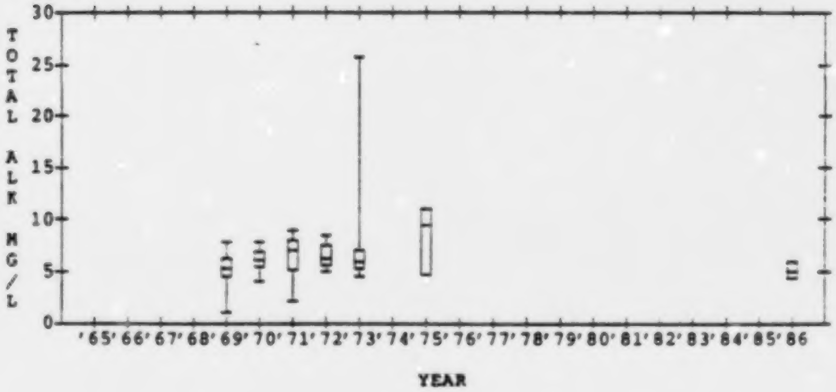


Figure 5.9

SPECIFIC CONDUCTANCE (uS/CM) OF ST CROIX RIVER AT ST CROIX
DATA FROM WQB GRAB SAMPLES

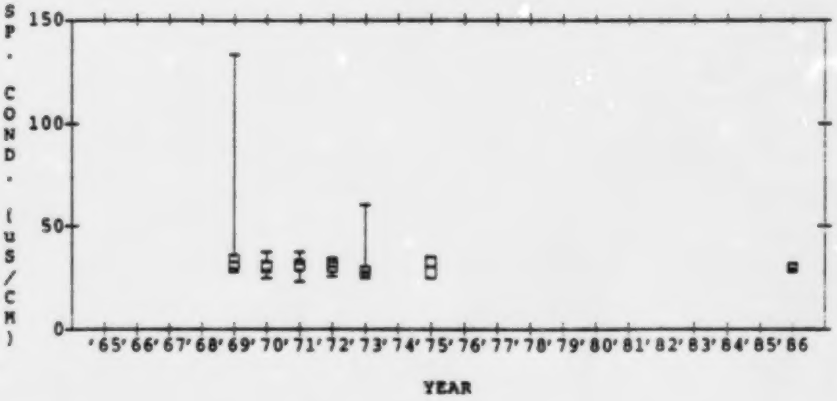


TABLE 5.3

CHANGES IN MILL OPERATIONAL PROCEDURES AND SELECTED WATER QUALITY PARAMETERS OVER TIME

Mill Processing/ Effluent Treatment	Time Period	Dominant Chemical Parameters	Dissolved Oxygen
Sulphite Process with no Treatment, irregular discharge rate and chemical composition.	1965-66	SO_4 (Sulphate) Mg^{++} (Magnesium)	Not analyzed
Kraft Process. No Treatment. Irregular discharge and chemical composition of effluent	1966-72	Na^+ (Sodium) Cl^- (Chloride) Ca^{++})Calcium) Total alkalinity	Not analyzed
Kraft Process. Primary Treatment. Irregular discharge	1972-78	Na^+ (Sodium) Cl^- (Chloride)	low, often below 5.0 mg/l during summer
Kraft Process. Secondary Treatment. Regular discharge	1978-86	Na^+ (Sodium) Cl^- (Chloride)	at or very near objective of 5.0 mg/l

(a) NA - Not Analyzed

Figure 5.10
SULFATE (MG/L) IN ST CROIX RIVER AT MILLTOWN
DATA FROM WQB GRAB SAMPLES

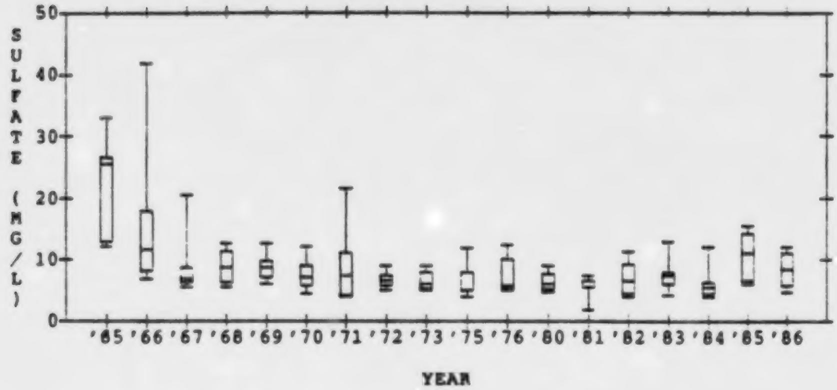


Figure 5.11
MAGNESIUM (MG/L) IN ST CROIX RIVER AT MILLTOWN
DATA FROM WQB GRAB SAMPLES

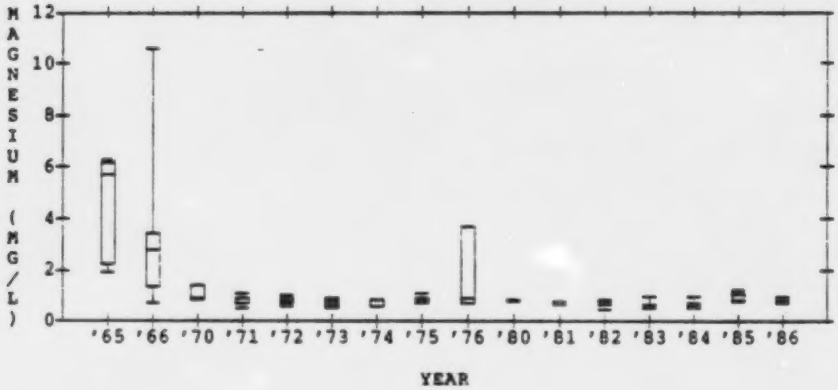


Figure 5.12
SODIUM (MG/L) IN ST CROIX RIVER AT MILLTOWN
DATA FROM WQB GRAB SAMPLES

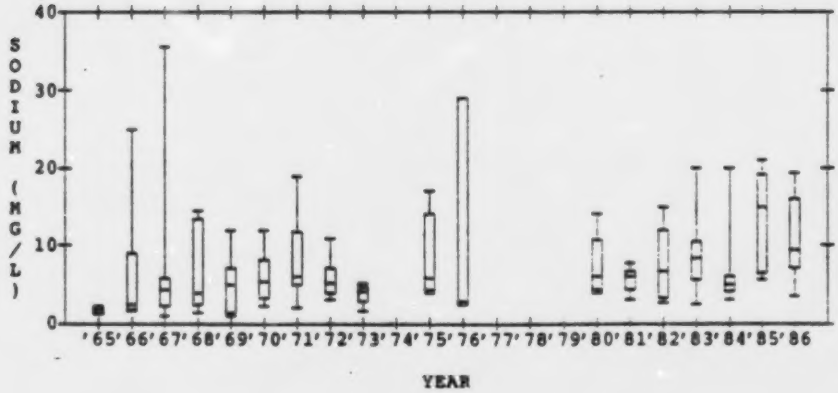


Figure 5.13
CHLORIDE (MG/L) IN ST CROIX RIVER AT MILLTOWN
DATA FROM WQB GRAB SAMPLES

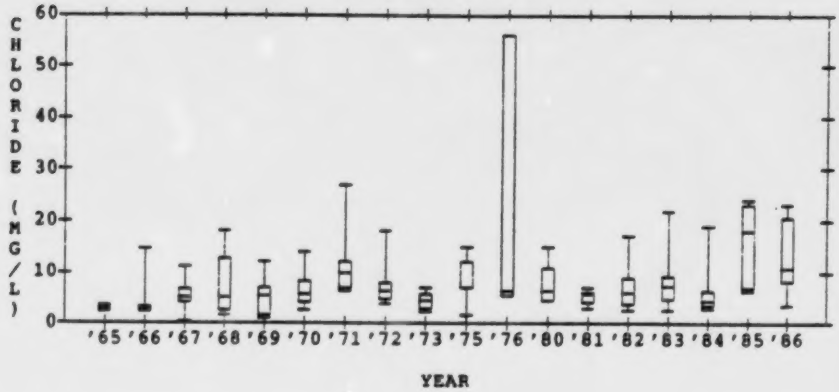


Figure 5.14
CALCIUM (MG/L) IN ST CROIX RIVER AT MILLTOWN
DATA FROM WQB GRAB SAMPLES

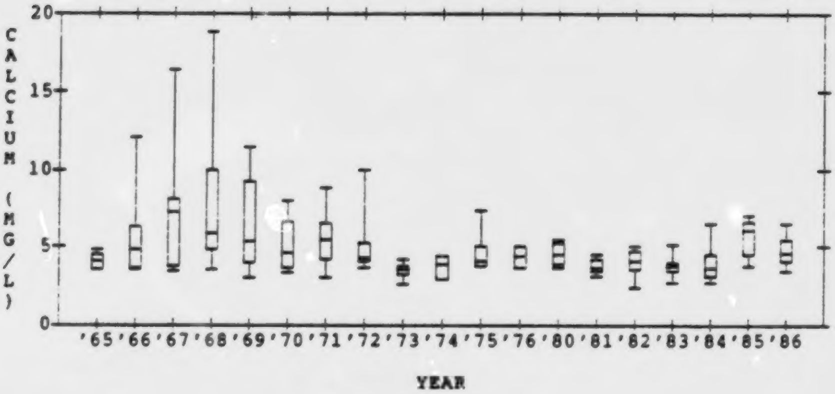
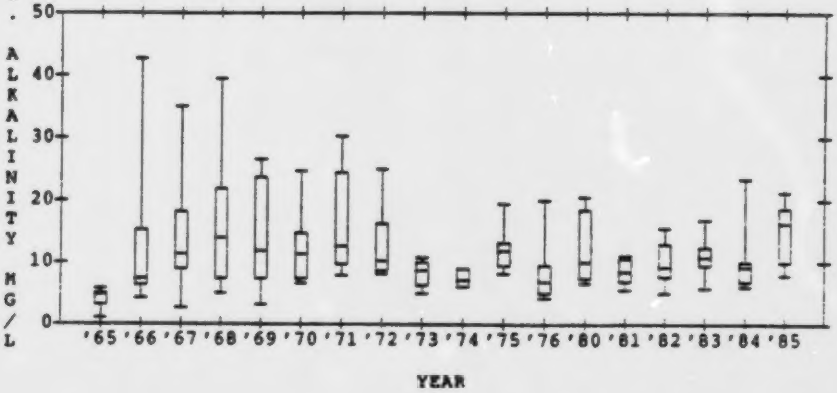


Figure 5.15
TOTAL ALKALINITY (MG/L AS CACO3) IN ST CROIX RIVER AT MILLTOWN
DATA FROM WQB GRAB SAMPLES



1972, Kraft effluent was discharged directly into the river with no treatment. Water quality was highly variable as illustrated by the minimum and maximum bars on box and whisker plots. Between 1972 and 1978, the effluent underwent primary treatment. This increased stability in the chemical dominance of the effluent and, to a lesser extent, the extreme variability of its discharge rate (Howell and Lockerbie, 1983a). Although median values were fairly stable, the range of concentrations of parameters such as specific conductance (Figure 5.16), sodium and chloride varied widely. Dissolved oxygen, for the months of July and August, which are traditionally periods of higher water temperatures, from 1975 to 1984, is plotted in Figures 5.17 and 5.18, respectively. These graphs were prepared from the AWQM data and they best illustrate that the dissolved oxygen levels were frequently below the water quality objective of 5 mg/l in 1980 and before, but is generally in compliance now. An incident which occurred in August, 1980, illustrates that dissolved oxygen can be a problem. An electrical malfunction at the Woodland Plant resulted in extremely low flows and dissolved oxygen levels as low as 0.5 mg/l. This incident is described more fully in the following pages.

With the introduction of secondary treatment in 1978, dissolved oxygen levels stabilized with mean concentrations of 7 mg/l. The box and whisker plots for dissolved oxygen from WQB grab samples at Milltown (Figure 5.19) indicate that 1986 samples are well above the water quality objective of 5.0 mg/l. Dissolved oxygen, as percent saturation (Figure 5.20) has a narrow range well above the water quality objective of 60%. The secondary treatment has had a stabilizing effect on the effluent and the river, and thus extreme values are less likely to occur. The variations seen in parameters such as specific conductance are more of a function of sampling frequency with the minima collected during spring snowmelt and maxima during low flow in the summer. The median values for specific conductance (Figure 5.16) in 1985 and 1986 are also a function of meteorological conditions. The higher 1985 median represents a warm dry summer and low base flows whereas 1986 was a cooler period with more precipitation resulting in more dilution.

5.4.2 WATER QUALITY VARIATION ALONG THE RIVER

This section of the report will focus on the current variation along the length of the river by examining the 1986 St. Croix River

Figure 5.16

SPECIFIC CONDUCTANCE (uS/CM) OF ST CROIX RIVER AT MILLTOWN
DATA FROM WQB GRAB SAMPLES

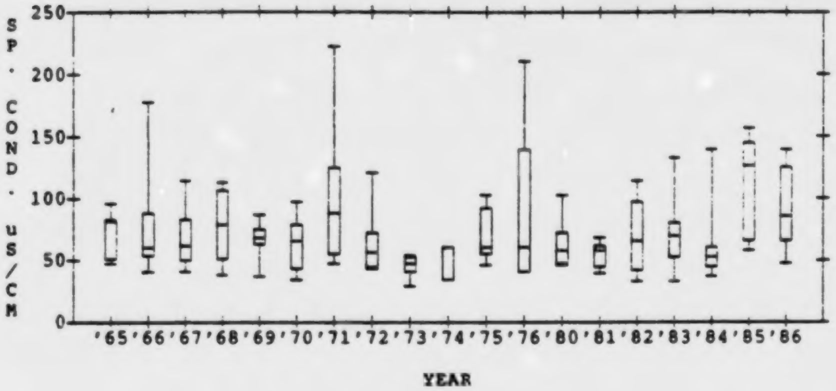


Figure 5.17

MINIMUM, MAXIMUM AND MEAN DISSOLVED OXYGEN (MG/L)
FOR MONTH OF JULY FOR PERIOD 1975 TO 1984
FROM U.S.G.S. PUBLISHED DATA FOR MILLTOWN A.W.Q.M.

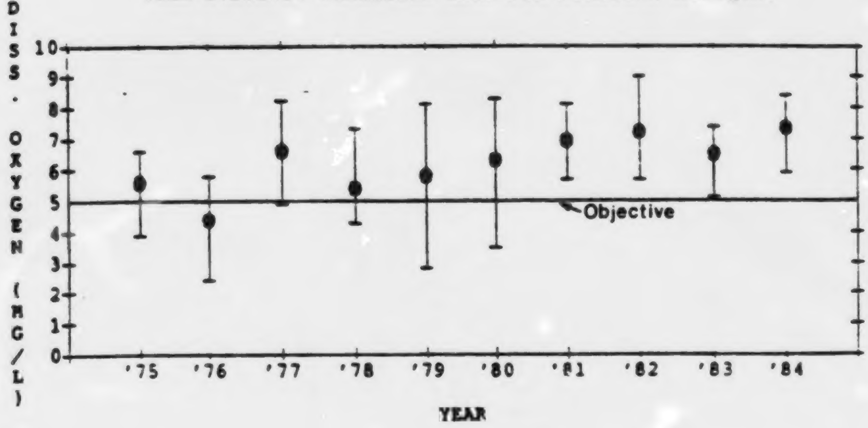


Figure 5.18

MINIMUM, MAXIMUM AND MEAN DISSOLVED OXYGEN (MG/L)
FOR MONTH OF AUGUST FOR PERIOD 1975 TO 1984
FROM U.S.G.S. PUBLISHED DATA FOR MILLTOWN A.W.Q.M.

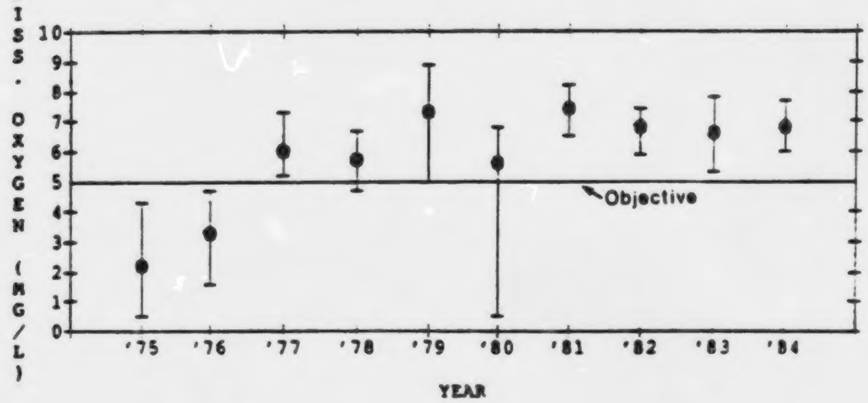


Figure 5.19
DISSOLVED OXYGEN (MG/L) IN ST CROIX RIVER AT MILLTOWN
DATA FROM WQB GRAB SAMPLES

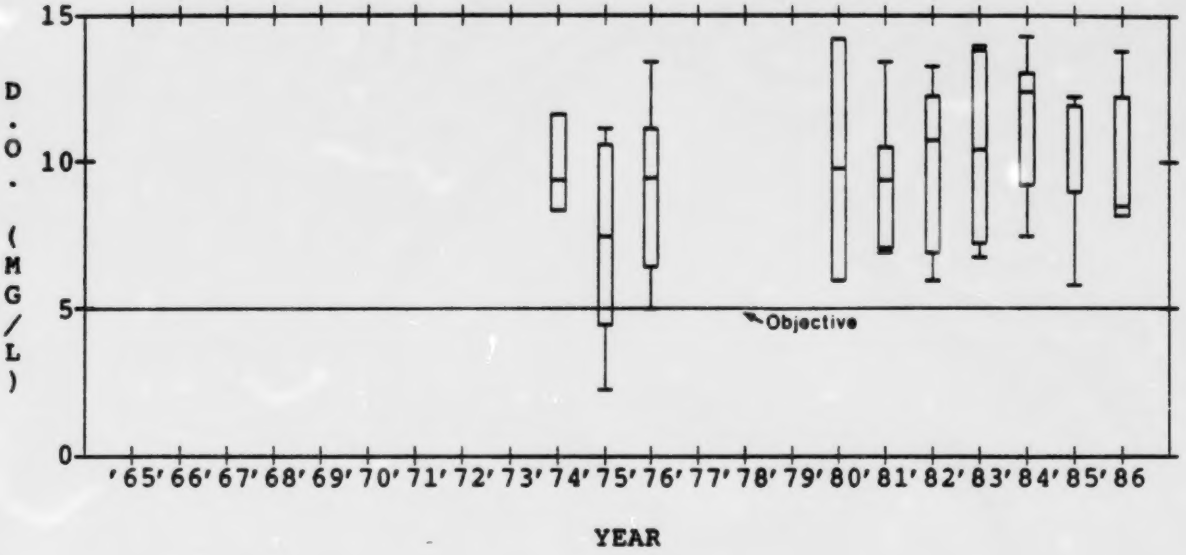
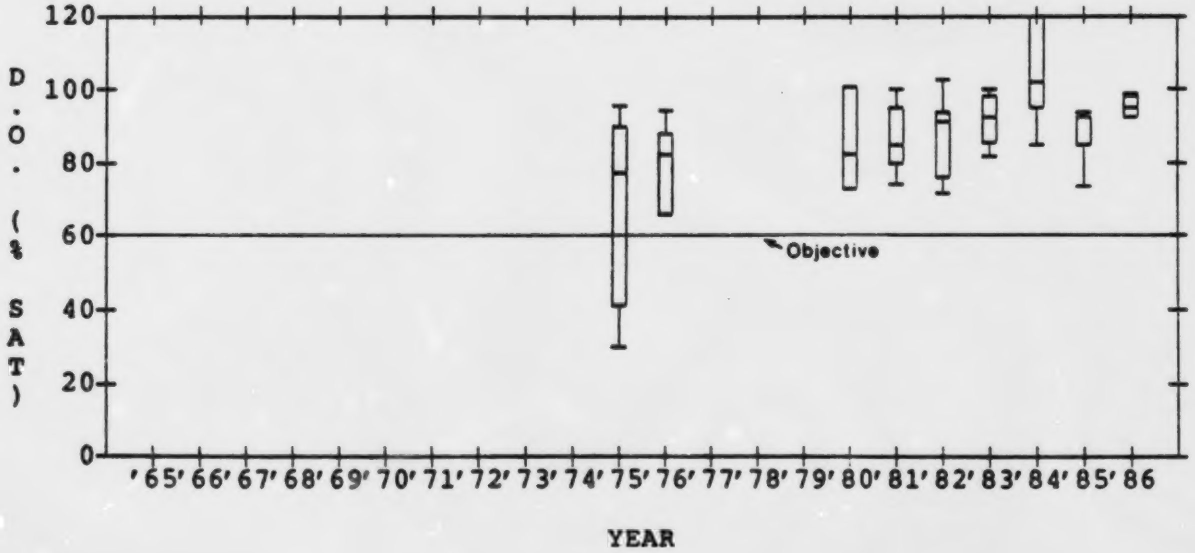


Figure 5.20
DISSOLVED OXYGEN (% SATURATION) IN ST CROIX RIVER AT MILLTOWN
DATA FROM WQB GRAB SAMPLES



monitoring data, which is the most recent and applicable data (Table 5.4). Figure 5.21 shows that there is little variation among stations located above Woodland. This is probably due to the fact that these stations drain similar terrain and are exposed to minimal human influence.

At Woodland, the major ion chemistry shifts from natural $CaCO_3$ dominance to sodium and chloride dominance because of the composition of the Kraft effluent (Figure 5.22). At Milltown, sodium and chloride are still the dominant ions, although their percentage of the total constituents is reduced. Colour and dissolved organic carbon (Figures 5.23 and 5.24) increase greatly at Woodland because of the effluent and remain higher than background at Milltown, although greatly reduced due to dilution. The sum of the constituents (Figure 5.21) is greatly increased at Woodland, and although it again diminishes at Milltown, is still higher than background.

It appears that when elevated parameter levels are observed at Woodland, it is usually diluted to 1 to 5 times background levels when measured at Milltown.

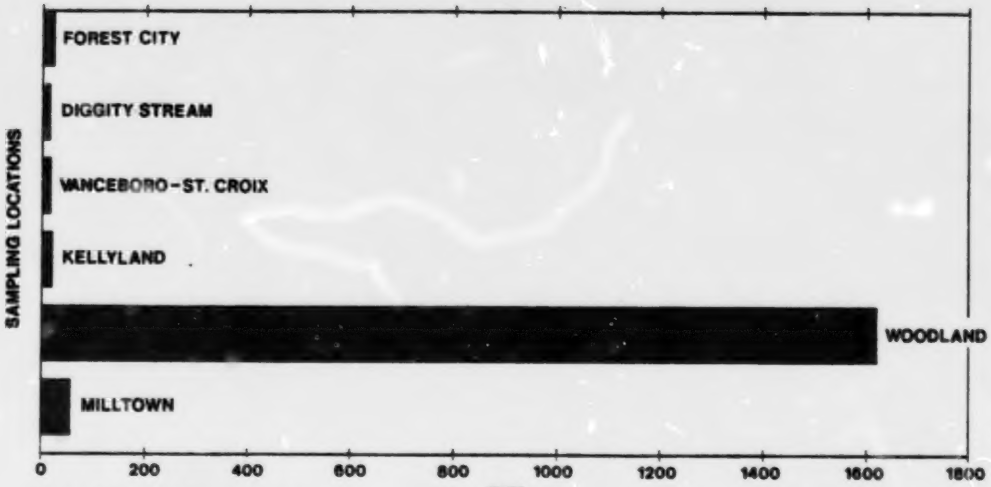
Another important phenomenon influencing water quality variation with distance along the river is the behaviour of the effluent plume. At the discharge site itself, Grass Island forms a physical barrier to lateral dispersion of the plume. Hence water quality varies, not only with distance along this section of the river due to a dilution effect, but laterally across the river as well. Aerial infrared photography and dye tests in 1976 indicated that the mill's effluent streamed along the U.S. (southwest) side of the river as far as Bailey Rips. Further studies and data analysis of the effluent plume's mixing and dilution have corroborated this finding (Howell and Lockerbie, 1983b), indicating that the effluent plume remains largely differentiated from the river mass at the Baring sampling station and is mixed into the river by the time it reaches the Milltown station. See Table 5.5 for the Baring data.

TABLE 5.4 : 1986 ST CROIX RIVER MONITORING DATA

0	STN	DATE	TIME	TEMP DEGC	DO MG/L	PH UNIT	COND US/CM	COLOR HU	TURB NTU	CA MG/L	NA MG/L	K MG/L	MG MG/L	CL MG/L	SO4 MG/L
1	00NB01AR0011	23-APR-86	945	6.0	12.1	6.8	30	L5.	0.4	3.6	0.9	0.28	0.57	1.4	3.2
2	00NB01AR0011	26-JUN-86	920	16.8	9.6	6.9	35	L5.	0.4	4.7	1.1	0.28	0.65		3.3
3	00NB01AR0011	28-AUG-86	950			6.8	35	L5.							
4	00NB01AR0011	28-AUG-86	954	17.3	9.4	6.7	36	L5.	0.3	4.3	1.1	0.30	0.67		3.3
5	00NB01AR0011	28-AUG-86	956	17.3	9.4	6.9	35	L5.	0.3	4.3	1.2	0.30	0.67		3.5
6	00NB01AR0029	23-APR-86	1115	6.7	10.7	5.9	30	40	0.5	2.2	2.1	0.43	0.41	3.5	3.7
7	00NB01AR0029	26-JUN-86	1130	18.2	9.4	6.4	28	50	0.7	2.4	1.9	0.43	0.42		3.2
8	00NB01AR0029	28-AUG-86	1140	17.7	9.3	6.6	27	30	0.7	2.2	2.0	0.47	0.44		3.1
9	00NB01AR0002	23-APR-86	1150	6.7	10.9	6.5	32	30	0.4	3.0	1.8	0.41	0.52	2.9	3.7
10	00NB01AR0002	26-JUN-86	1150	17.5	9.5	6.6	28	15	0.5	3.1	1.3	0.33	0.47		3.3
11	00NB01AR0002	28-AUG-86	1210	17.5	9.0	6.7	29	10	0.5	3.1	1.4	0.33	0.54		3.3
12	00NB01AR0013	07-FEB-86	1306	0.5	14.0	6.4	37	45	0.6	3.9	1.7	0.46	0.86	2.9	5.2
13	00NB01AR0013	25-MAR-86	1140	1.0	11.6	6.5	39	35	0.9	4.2	1.6	0.39	0.88	2.3	4.8
14	00NB01AR0013	23-APR-86	1245	8.6	11.4	6.5	32	45	0.7	3.4	1.4	0.41	0.73	2.2	3.8
15	00NB01AR0013	23-APR-86	1235	8.6	11.4	6.5	33	40	0.7	3.4	1.3	0.39	0.73	2.2	4.0
16	00NB01AR0013	23-APR-86	1240	8.6	11.4	6.2	32	40	0.6	3.4	1.3	0.37	0.72	2.1	4.2
17	00NB01AR0013	26-JUN-86	1400	20.3	9.0	6.7	30	20	0.7	3.2	1.5	0.33	0.58		3.3
18	00NB01AR0013	28-AUG-86	1320	17.8	8.6	6.6	30	40	0.8	3.4	1.5	0.33	0.71		3.5
19	00NB01AR0013	13-NOV-86	1535		13.7	6.8	33	35							
20	00NB01AR0013	13-NOV-86	1540			6.9	34	35							
21	00NB01AR0013	13-NOV-86	1545			6.8	34	35							
22	00NB01AR0014	07-FEB-86	1435	15.0	8.2	7.4	2630	G1000.	40.0	62.0	511.0	29.00	5.50	500.0	252.0
23	00NB01AR0014	07-FEB-86	1437	15.0	8.2	7.5	2620	G1000.	39.0	62.0	511.0	37.00	5.50	500.0	252.0
24	00NB01AR0014	07-FEB-86	1430	15.0	8.2	7.3	2620	G1000.	42.0	62.0	485.0	27.00	5.80	500.0	250.0
25	00NB01AR0014	23-APR-86	1340	18.2	8.2	-	2380	G1000.	7.0	57.0	437.0	18.20	5.50	450.0	237.8
26	00NB01AR0014	26-JUN-86	1500	27.8	6.8	7.4	2590	G1000.	53.0	69.0	456.0	19.00	5.90		232.0
27	00NB01AR0014	28-AUG-86	1500		7.7	7.8	1860	G1000.							
28	00NB01AR0014	13-NOV-86	1435		8.6	7.5	2450	G1000.							
29	00NB01AR0001	02-JAN-86	1300	0.0		7.0	104	60	1.5	5.6	12.1	0.92	0.97	13.5	11.1
30	00NB01AR0001	07-FEB-86	1530	0.2	13.8	6.6	72	60	1.4	4.3	7.5	0.78	0.87	8.4	8.1
31	00NB01AR0001	12-MAR-86	1400	1.5		6.9	122	50	2.0	5.2	15.2	0.91	0.95	22.0	9.6
32	00NB01AR0001	25-MAR-86	1135	0.0		6.7	85	50	2.6	4.6	9.5	0.73	0.84	10.5	8.4
33	00NB01AR0001	25-MAR-86	1137	0.0		6.7	85	55	2.2	4.7	9.4	0.72	0.84	10.8	8.4
34	00NB01AR0001	25-MAR-86	1139	0.0		6.7	86	55	2.4	4.6	9.3	0.72	0.84	10.7	8.6
35	00NB01AR0001	23-APR-86	1445	8.6	10.9	6.8	58	55	2.1	3.4	6.2	0.57	0.68	6.9	6.5
36	00NB01AR0001	14-MAY-86	1330	1.0		6.7	66	60	2.3	4.0	7.2	0.63	0.74		5.9
37	00NB01AR0001	14-MAY-86	1335	1.0		6.6	66	60	2.3	4.0	6.8	0.61	0.75		5.7
38	00NB01AR0001	14-MAY-86	1332	1.0		6.5	67	55	2.0	4.0	7.9	1.05	0.75		5.9
39	00NB01AR0001	26-JUN-86	1535	18.7	8.2	6.9	140	80	2.9	5.5	19.3	1.10	0.88		12.3
40	00NB01AR0001	26-JUN-86	1537	18.7	8.2	6.9	140	90	4.1	5.5	19.3	1.10	0.88		11.1
41	00NB01AR0001	26-JUN-86	1540	18.7	8.2	6.8	140	90	3.5	6.5	19.0	1.20	0.87		11.2
42	00NB01AR0001	04-JUL-86	930	18.0		6.7	99	60	1.3	4.9	12.3	0.89	0.80		7.9
43	00NB01AR0001	28-AUG-86	1515	18.2	8.5	6.4	57	60	2.2	4.1	5.4	0.57	0.74		4.9
44	00NB01AR0001	08-SEP-86	1320	14.0		6.7	47	50	1.0	4.4	3.5	0.46	0.79		4.7
45	00NB01AR0001	13-NOV-86	1240		12.2	7.0	127	70							

TABLE 5.4 :1986 ST CROIX RIVER MONITORING DATA

	SO4-IC MG/L	ALKAL MG/L	IRON MG/L	MANG MG/L	CU MG/L	PB MG/L	HG UG/L	AL MG/L	CD MG/L	PO4 MG/L	TN MG/L	NO3 MG/L	DOC MG/L
1		7.8	L.05		L.002	L.002	L.02	0.020	L.001	0.005	0.12	0.02	3.2
2		9.6			L.002	L.002		0.190	L.001	0.004	L.1	L.01	3.2
3		9.7			L.002	L.002	L.02	L.010	L.001	0.004			
4		9.8			L.002	L.002	L.02	L.010	L.001	0.004	L.1	0.01	2.8
5		9.8			L.002	L.002	L.02	L.010	L.001	0.003	L.1	L.01	3.3
6	3.0	2.7	0.18		L.002	L.002	L.02	0.120	L.001	0.015	0.21	0.05	7.5
7	2.7	3.1	0.15		L.002	L.002		0.170	L.001	0.017	0.12	L.01	7.6
8		3.6	0.12		L.002	L.002	L.02	0.052	L.001	0.013	0.14	L.01	7.5
9		4.4				L.002	L.02	0.080	L.001	0.011	0.22	0.04	6.2
10		5.0				L.002		0.170	L.001	0.009	0.12	L.01	4.7
11		5.9				L.002	L.02	0.024	L.001	0.006	0.11	L.01	5.2
12	4.9	5.7	0.14		L.002	L.002	L.02	0.088	L.001	0.007	0.20	0.04	7.3
13	4.0	8.1									0.23	0.12	6.5
14	3.4	6.1	0.12		L.002	L.002	L.02	0.085	L.001	0.009	0.18	0.02	7.2
15	3.2	6.2	0.15		L.002	L.002	L.02	0.091	L.001	0.011	0.17	0.02	7.5
16	3.3	6.2	0.15		L.002	L.002	L.02	0.097	L.001	0.011	0.20	0.03	7.5
17		6.2	0.12		L.002	L.002		0.320	L.001	0.015	0.12	L.01	5.7
18	3.0	6.6	0.16		L.002	L.002	L.02	0.041	L.001	0.010	0.14	0.03	7.7
19		7.4	0.17		L.002	L.002	L.02	L.050	L.001	0.011			
20		7.5	0.16		L.002	L.002	L.02	L.050	L.001	0.010			
21		7.5	0.16		L.002	L.002	L.02	L.050	L.001	0.008			
22		336.5	0.51		L.002	0.004	0.02	3.100	0.009		4.60	3.40	11.0
23		337.7	0.52		L.002	0.003	L.02	3.100	0.002		4.70	4.10	11.0
24		334.0	0.52		0.003	0.003	0.02	3.200	0.001			3.10	83.0
25			0.69		0.009	0.008	0.03	3.100	0.004		3.60	3.50	96.0
26	215.0	238.6	0.82		0.008	0.006		3.100	0.003		6.80	5.50	76.0
27		166.7	0.51		0.006	0.004	0.02	2.200	0.001				
28		250.0	0.54		L.002	L.002	L.02	2.500	0.001				
29	10.0	14.6	0.17	0.07	L.002						0.28	0.17	9.6
30	7.0	9.0	0.16		L.002	0.002	L.02	0.150	0.001	0.016	0.21	0.05	8.7
31	8.1	14.5	0.21	0.07	L.002						0.24	0.14	7.5
32	7.1	12.5	0.16	0.07	L.002						0.24	0.06	8.0
33	7.1	12.7	0.19	0.07	L.002						0.25	0.10	8.4
34	7.3	12.7	0.14	0.07	L.002						0.24	0.11	8.0
35	5.4	8.0	0.13		L.002	0.002	L.02	0.120	L.001	0.029	0.19	0.07	6.5
36	6.0	8.5	0.14	0.05	L.002						0.16	0.06	6.4
37	5.9	8.5	0.15	0.05	L.002						0.17	0.06	6.8
38	6.1	8.3	0.13	0.05	L.002						0.15	0.05	6.9
39	10.8	17.4	0.22		L.002	L.002		0.310	L.001	0.052	0.22	0.12	8.8
40	10.9	15.8	0.23		L.002	L.002		0.160	L.001	0.051	0.29	0.16	8.6
41	10.9	15.7	0.23		L.002	L.002		0.190	L.001	0.052	0.21	0.10	8.8
42	7.8	12.4	0.18	0.09	L.002						0.23	0.12	7.3
43	4.5	8.8	0.25		L.002	L.002	L.02	0.093	L.001	0.027	0.19	0.03	9.4
44	4.0	9.7	0.19	0.05	0.005						0.14	0.02	8.9
45		15.4	0.19		L.002	L.002	L.02	0.160	L.001	0.036			



Note: 1986 Grab Sampling Data.

Figure 5.21 Variation in Sum of Constituents at Six Sampling Stations Between Grand Lake Outlet and Milltown on the St. Croix River Based on Mean of 1986 Grab Sampling Data

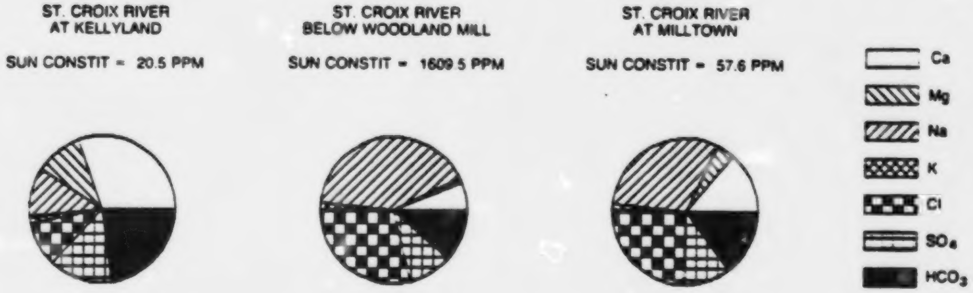


Figure 5.22 Major Ion chemistry of St. Croix River 1986 Sampling

Figure 5.23

VARIATION IN WATER COLOUR AT SIX SAMPLING STATIONS BETWEEN GRAND LAKE OUTLET AND MILLTOWN ON THE ST CROIX RIVER BASED ON MEAN OF 1986 GRAB SAMPLING DATA

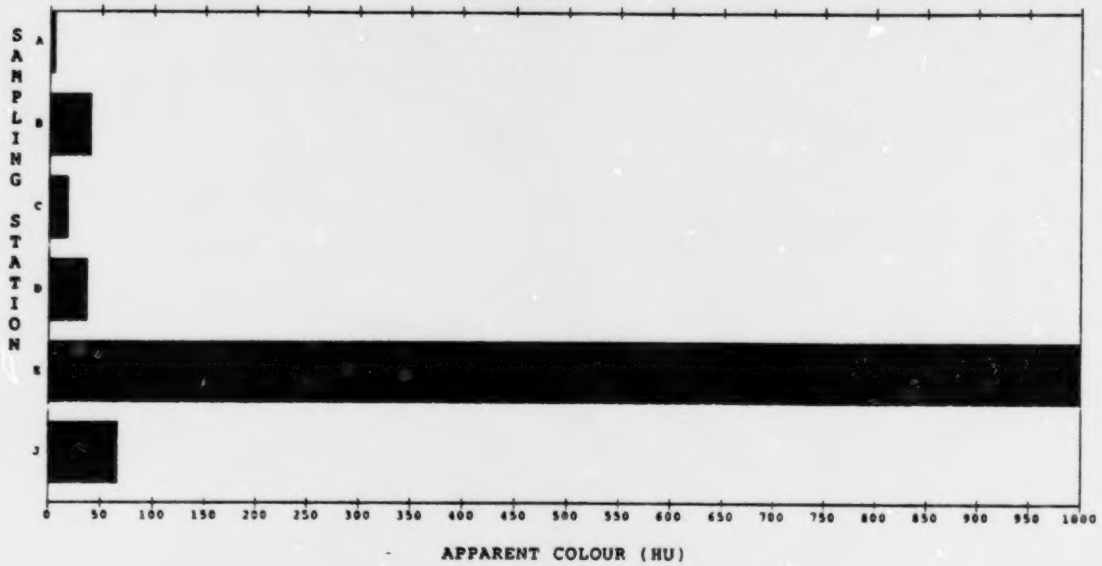


Figure 5.24

VARIATION IN DISSOLVED ORGANIC CARBON AT SIX SAMPLING STATIONS BETWEEN GRAND LAKE OUTLET AND MILLTOWN ON THE ST CROIX RIVER BASED ON MEAN OF 1986 GRAB SAMPLING DATA

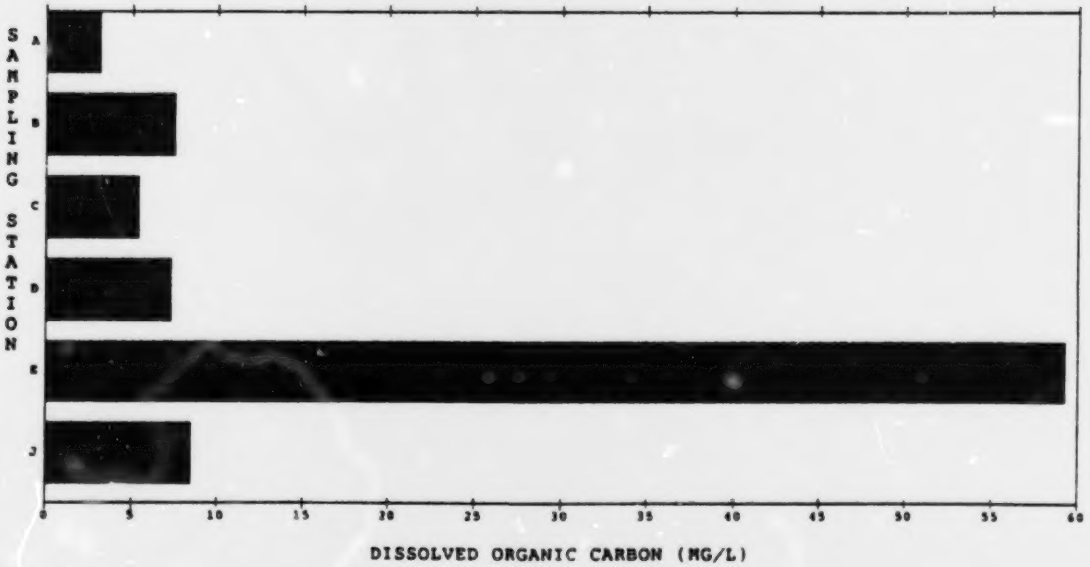


TABLE 5.5

MEASUREMENTS OF SELECTED WATER QUALITY PARAMETERS AT THREE STATIONS AT BARING

Date	Station	Temp. °C	Oxygen mg/l	Oxygen %Satn	Sp.Cond uS/cm	Lab. pH	Colour (H.U.)	Alkalinity mg $CaCO_3$/l
29-04-82	US	7.5	11.8	102	39	6.3	35	6.0
	Mid-River	7.5	11.9	102	30	6.3	30	5.0
	Canada	7.5	12.0	103	25	6.3	30	5.0
03-06-82	US	17.5	6.7	72	156	7.0	100	24.5
	Mid-River	17.5	7.8	84	91	6.9	80	14..0
	Canada	17.4	7.9	85	76	6.9	70	12.5
21-07-82	US	23.3	6.0	72	178	6.8	100	17.7
	Mid-River	23.6	6.2	75	104	6.8	50	12.6
	Canada	23.6	6.1	73	92	6.7	50	11.2
14-10-82	US	11.5	9.8	93	80	6.2	50	5.5
	Mid-River	11.5	9.7	92	66	6.6	40	10.0
	Canada	11.5	9.8	93	50	7.1	40	9.5
19-01-83	US	-	-	-	128	6.6	100	14.6
	Mid-River	-	-	-	62	6.6	80	8.8
	Canada				58	6.6	70	8.2
31-03-83	US	2.0	12.6	94	90	6.8	88	11.1
	Mid-River	1.8	13.8	102	44	6.6	40	6.4
	Canada	1.7	13.8	102	40	6.5	35	6.4

5.4.3 CHANGES WITH FLOW DISCHARGE

The box and whisker plots for the St. Croix River at St. Croix station indicate little variation for the parameters measured. From 1969 to 1973, the plots represent samples collected on a monthly frequency, therefore it is probable that the samples were collected under a variety of flow regimes. There are a few outliers for specific conductance, sulphate and total alkalinity which are suspect.

During the period (1967-1972) when untreated Kraft effluent was discharged directly into the river, both the chemical composition and the discharge rate of the effluent were highly variable. Although this variability was reduced with the adoption of primary effluent treatment in 1972, the most noticeable improvement corresponded to the addition, construction and operation of the secondary treatment facility in 1977-1978. During 1978-1981 period, there were good relationships between specific conductance and mean daily discharge as well as specific conductance and the major ions (Howell and Lockerbie, 1983a). This illustrates that river water quality below Woodland is a function of the combined effects of pulp mill effluent chemistry and the extent of dilution by river discharge.

Discharge appears to have little effect on specific conductance above Woodland where river water is pristine, but a decrease in conductance with increasing flow is evident at Baring and Milltown where mill effluent would be diluted more with increasing flow discharge. The Woodland station is sampled in the effluent plume. Figure 5.25 indicates that discharge bears little relationship with specific conductance, but the effluent concentration seems to provide a dramatic increase at the Woodland station where dilution has not yet occurred.

This relationship between specific conductance and discharge for water receiving mill effluent is further considered using one sampling station. A relationship between these two parameters is shown in Figure 5.26 using 1982 AWQM (Milltown) data. The outliers (indicated by large dots) were measured in September when mill operations were stopped for a period of four weeks. Thus, these outlying values are further indicative of the lack of relationship between discharge and specific conductance. Therefore the relationship between discharge and specific conductance is affected by the concentration of the effluent which obviously reduces when the mill is not operational or when dilution occurs.

The strength and importance of the relationship between dissolved oxygen and discharge is illustrated by an event which began on August 10, 1980 (Figure 5.27). Discharge data in this figure are based on mean daily flow and do not reflect fluctuations in instantaneous discharge. These short term fluctuations of discharge, in combination with warm water temperatures, led to a gradual sag of oxygen levels on August 22. On August 28, the control gates at Grand Falls dam closed causing the flow to drop well below the 21.2 cms (750 cfs) for several hours even though no technical violation occurred on a mean daily basis. During this period, the treated effluent continued to be discharged undiminished. Without sufficient river dilution, the residual BOD in the wastes nearly exhausted the available oxygen, which resulted in a low value of 0.5 mg/l. As indicated by the minimum and maximum bars for oxygen on August 28, the levels ranged from 0.5 to 4.5 mg/l. The gates

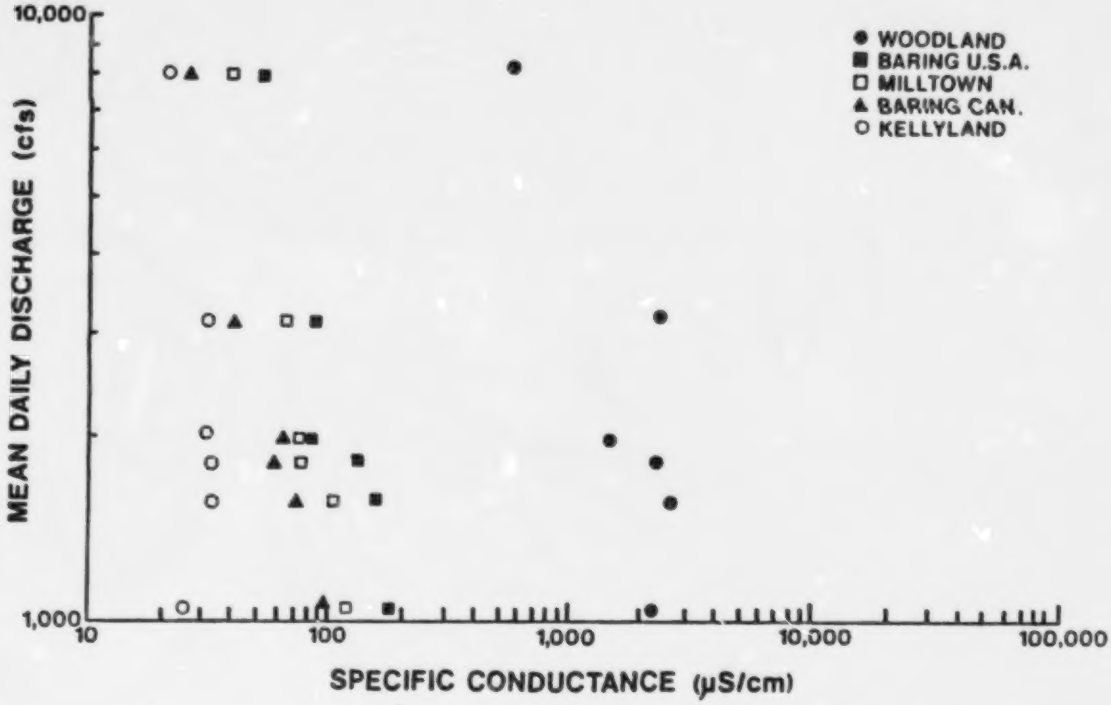


Figure 5.25 Comparison of Discharge and Specific Conductance for Five St. Croix River Sampling Stations

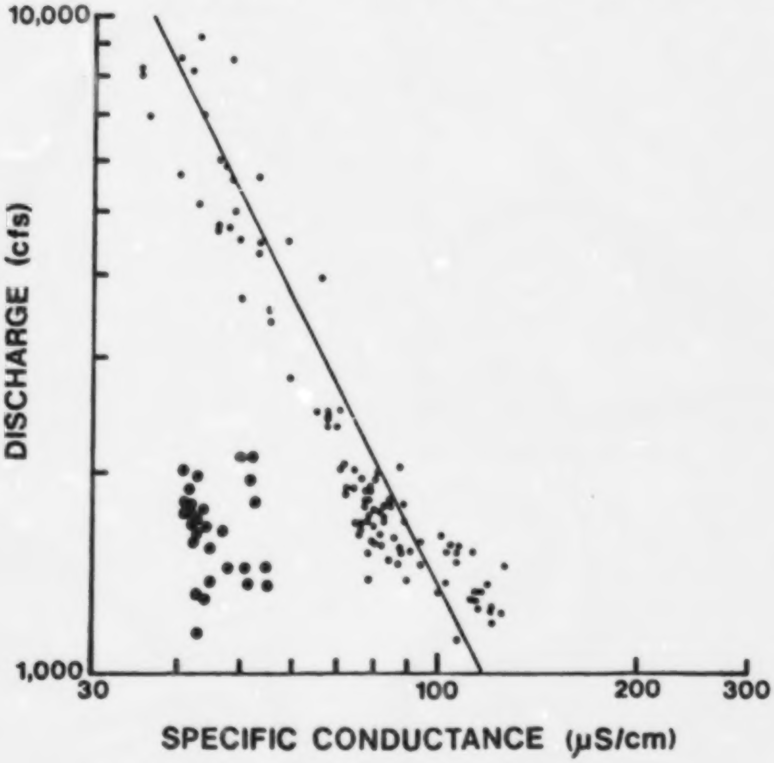
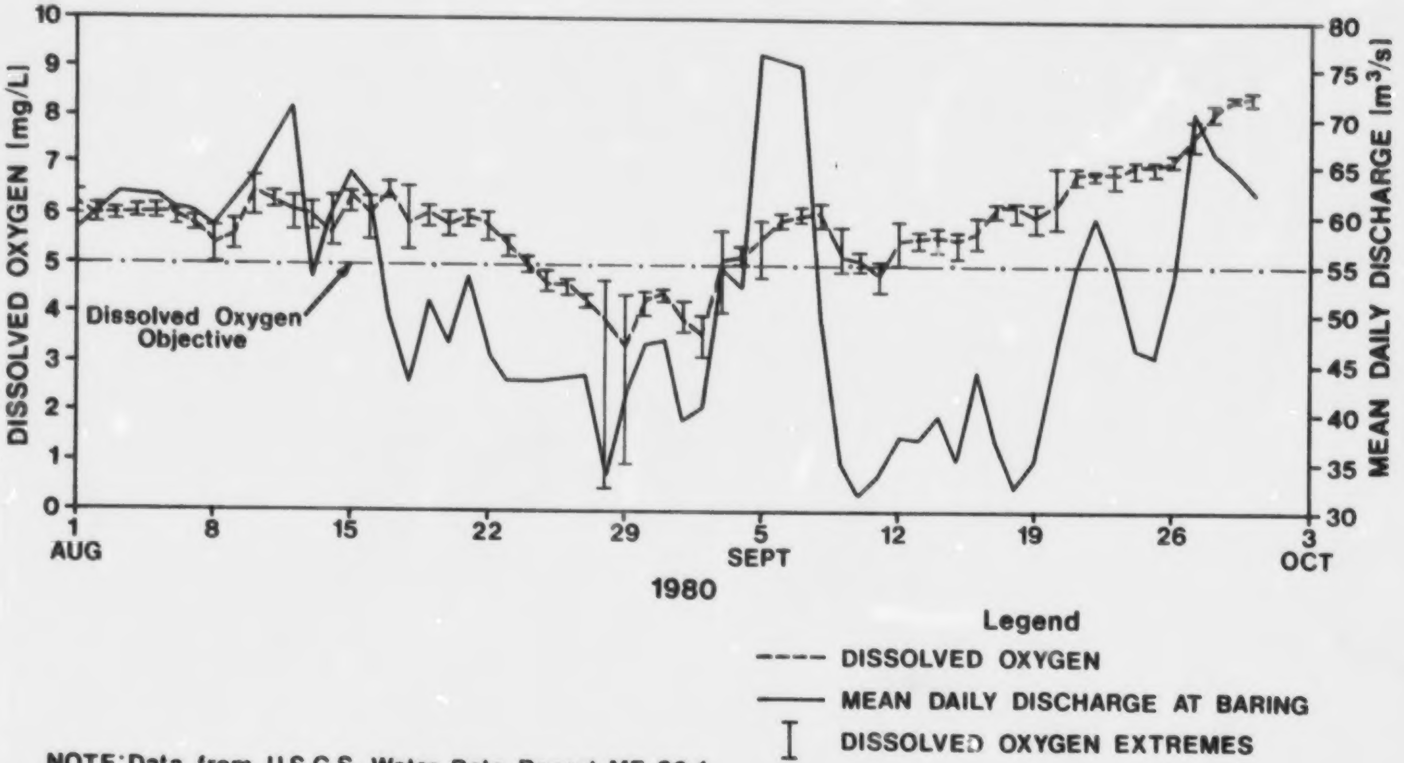


Figure 5.26 Relationship Between Discharge and Milltown AWQM Specific Conductance Measurements for the Period April 1982-Sept. 1982

Daily Mean, Maximum and Minimum Dissolved Oxygen (mg/l)
Measured by U.S.G.S. Milltown Auto Monitor



NOTE: Data from U.S.G.S. Water Data Report ME-80-1.

Figure 5.27

were reopened and dissolved oxygen began to recover slowly. A series of manipulations such as cutting effluent flow and increasing discharge were used to stabilize the dissolved oxygen after the event. This accounts for the extremely high flows on September 5 and stable dissolved oxygen during reduced flows for September 9 to September 19.

It should be noted that, in recent years, under operational conditions and established maintenance flows, dissolved oxygen has complied with the water quality objective.

To improve the aesthetic quality of the river, it has been suggested the maintenance flow should be increased 25 to 30% (from 21.2 to 27.5 m^3/s). There is little doubt that this increase flow would have an overall positive effect on the water quality below Woodland, as well as improve the appearance of the river. However, according to a nomograph which is discussed further in Section 5.5.1, increased flow will not greatly influence dissolved oxygen levels below Woodland. It could result in large fluctuations in Spednic Lake levels and adverse effects on fisheries (Cronin, 1985) and other recreational uses of the lake.

5.5 FOCUS ON WATER QUALITY AND BASIN ACTIVITIES

5.5.1 PULP AND PAPER INDUSTRY

The evidence presented in Section 5.4 indicates that forestry operations in those areas upstream of the mill site in Woodland have not impacted on the river quality during the period of record. The overwhelming impact is the effluent from the mill itself.

The 1986 water quality data from the six sampling sites may be put into perspective by comparing it to the water quality objectives established by the PACB for the St. Croix River, and to guidelines for the protection of freshwater aquatic life (CRREM, 1987). The objectives, guidelines and detection limits of the methodology were presented previously (Table 5.1).

According to Figures 5.28 and 5.29, minimum values in 1986 were well above the water quality objective of 5.0 mg/l dissolved oxygen and 60% saturation. Oxygen values were only determined twice at Grand Lake outlet (Forest City Stream), and therefore were not included in the box plots.

Figure 5.28
DISSOLVED OXYGEN (MG/L) IN ST CROIX RIVER
1986 GRAB SAMPLING DATA

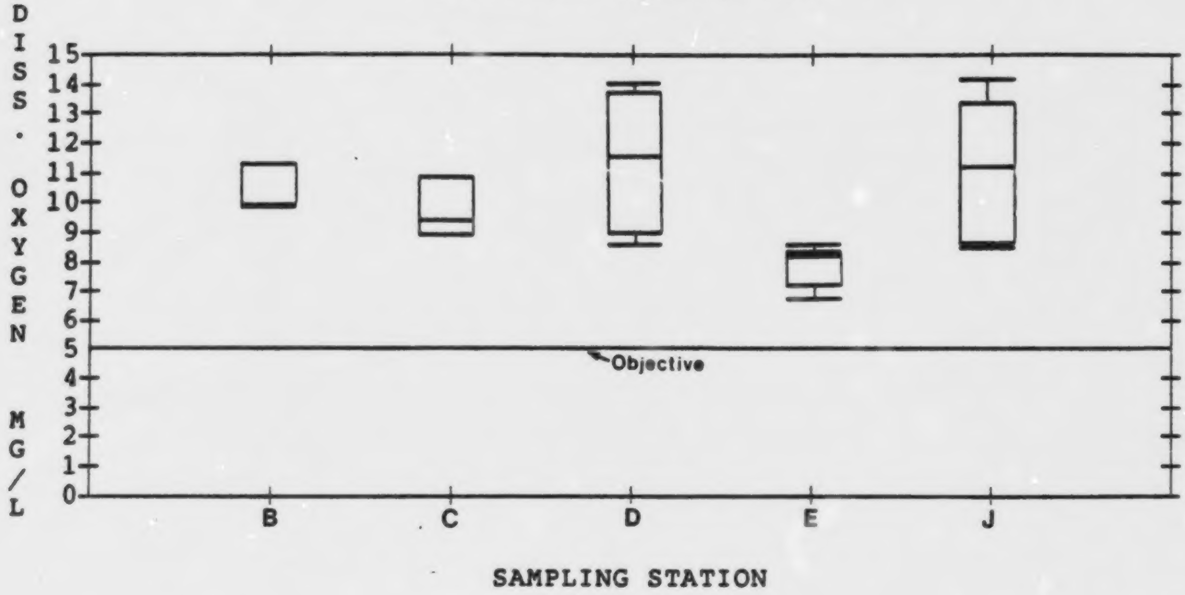
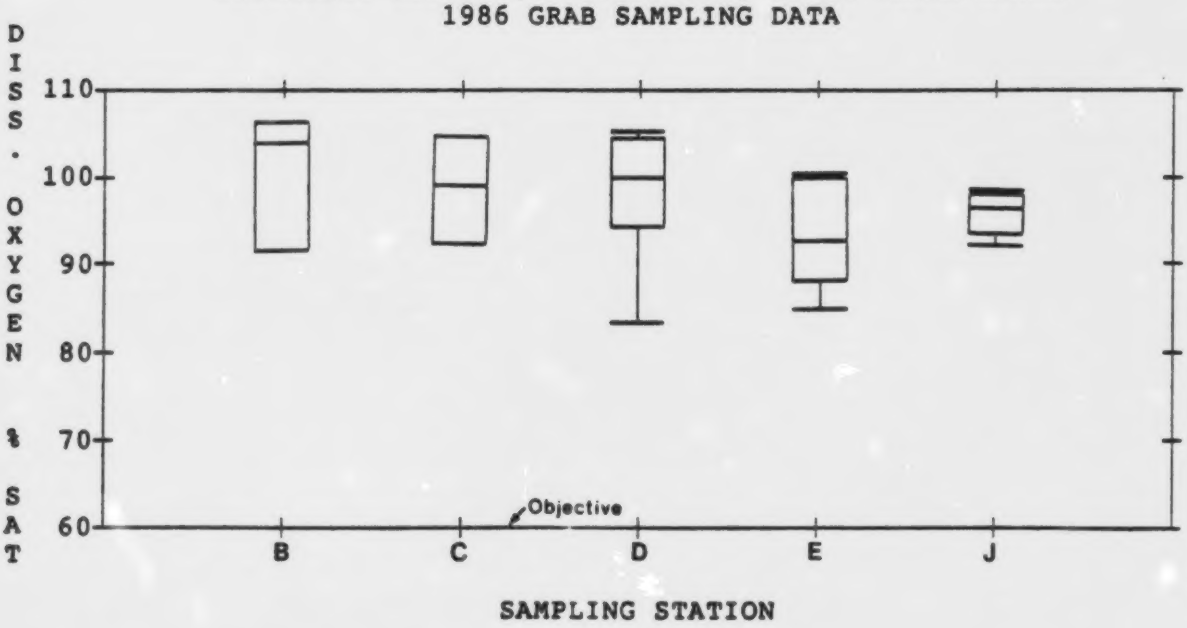


Figure 5.29
DISSOLVED OXYGEN (% SATURATION) IN ST CROIX RIVER
1986 GRAB SAMPLING DATA



pH in 1986 samples met the Water Quality Objectives of 6.0 to 8.5 pH units at all sites except for a pH of 5.9 recorded at Diggity Stream in April, as shown in Figure 5.30. The lowering of pH at that time may have been in response to snowmelt.

The guideline for aluminum is 0.100 mg Al/l in natural waters with a pH greater than 6.5. With background levels above Woodland ranging from the detection limit of 0.01 to 0.320 mg/l, and a median of 0.095 mg/l, Figure 5.31 shows that all these sites had aluminum slightly above the guideline. Elevated levels at Woodland (0.310 to 3.1 mg/l) probably reflect the use of alum ($Al_2(SO_4)_3 \cdot 10H_2O$) in the fresh water treatment at the Georgia-Pacific Pulp Mill. Although the aluminum concentration greatly exceeds the guidelines at some sites, they may not be significant to the protection of aquatic life. It has been shown that organically bound aluminum is not toxic to fish, and has been reported that, in waters high in dissolved organic carbon, non-labile (complexed) aluminum forms the predominant fraction of total aluminum (Clair et al, 1984). At Milltown values had returned to background levels.

Figures 5.32 and 5.33 indicate that cadmium and copper were not detected above the mill, however, the guidelines of 0.0002 mg/l and 0.005 mg/l respectively were exceeded at Woodland. At Woodland, cadmium ranged from the detection limit of 0.001 to 0.009, while at Milltown, it was not detected except for one value of 0.001 mg/l. It should be noted that the detection limit for cadmium is five times greater than the suggested guidelines, for the most part making it impossible to compare levels in the river to the guideline.

For copper, only four of 34 samples in 1986 exceeded the detection limit of 0.002. The four positive values from Woodland ranged from 0.003 to 0.009, three of which slightly exceeded the guideline of 0.005 mg/l.

Iron is a heavy metal which is commonly found in natural fresh waters, particularly those which are highly coloured (Howell and Lockerbie, 1983b). For this reason, the guideline is fairly high at 0.300 mg/l. Figure 5.34 indicates that, of the four sites where iron was analyzed, only the Woodland site exceeded the guideline on all occasions. At Woodland, the values ranged from 0.51 to 0.82 mg/l.

Figure 5.30
pH AT SIX SAMPLING STATIONS IN ST CROIX RIVER
1986 GRAB SAMPLING DATA

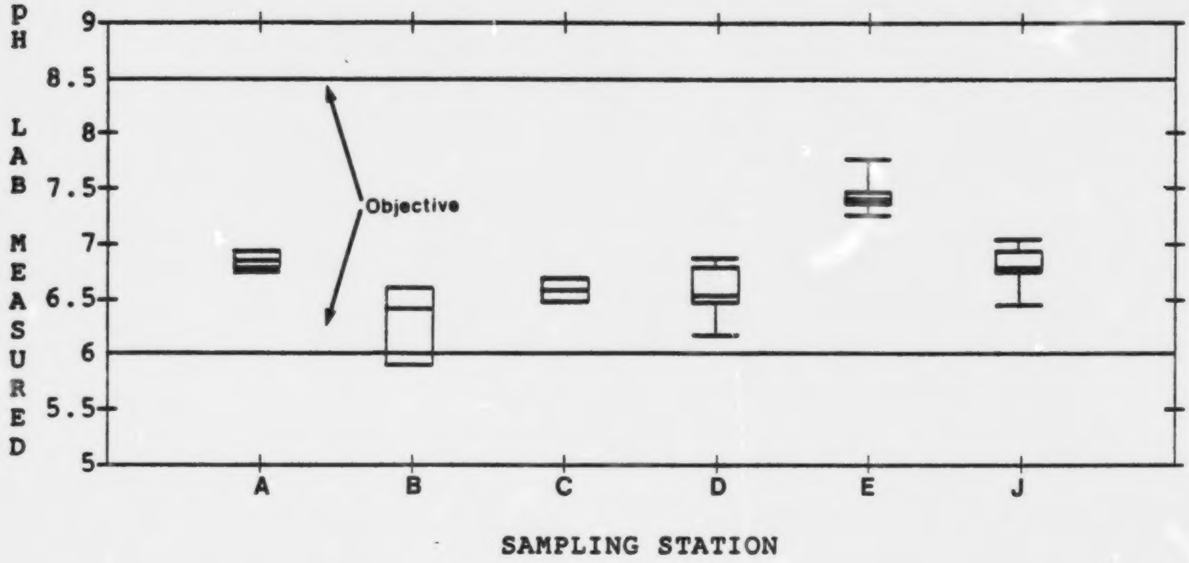


Figure 5.31
EXTRACTABLE ALUMINUM (MG/L) IN ST CROIX RIVER
1986 GRAB SAMPLING DATA

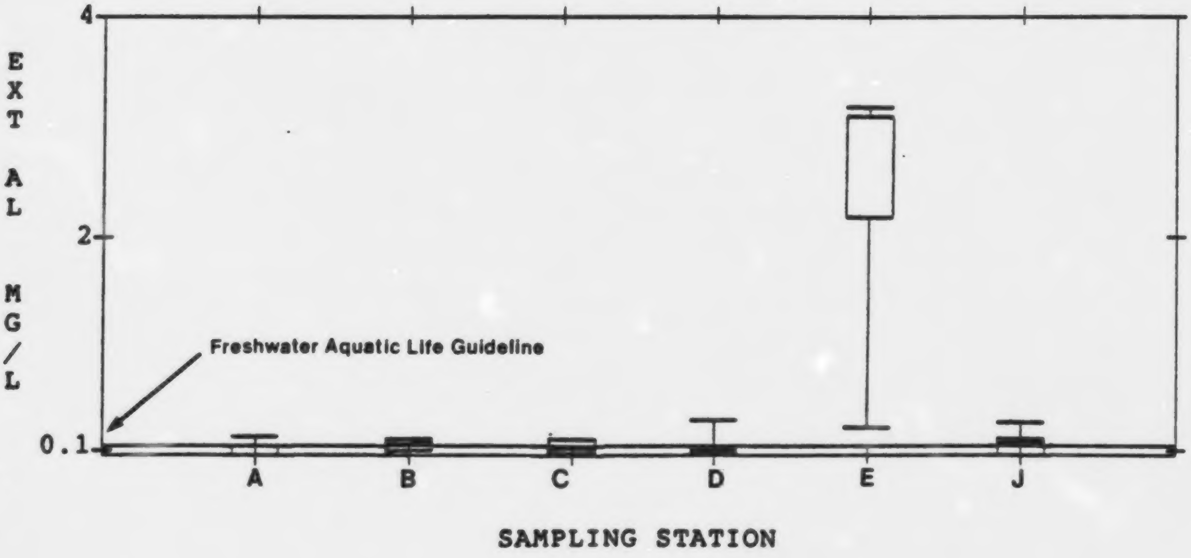


Figure 5.32
EXTRACTABLE CADMIUM (MG/L) IN ST CROIX RIVER
1986 GRAB SAMPLING DATA

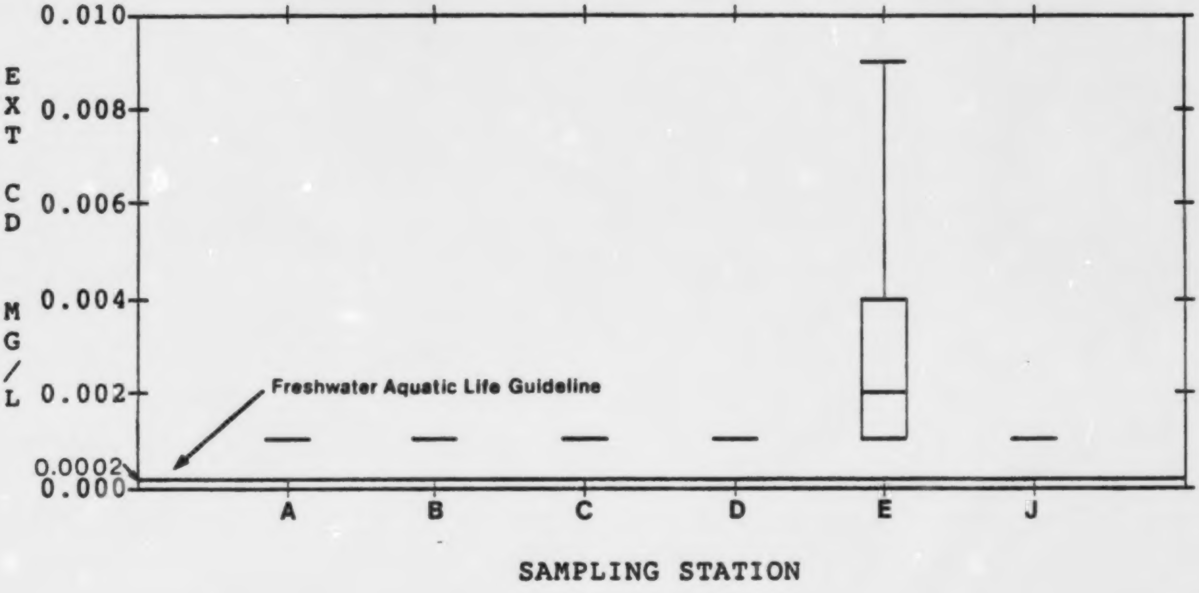


Figure 5.33
EXTRACTABLE COPPER (MG/L) IN ST CROIX RIVER
1986 GRAB SAMPLING DATA

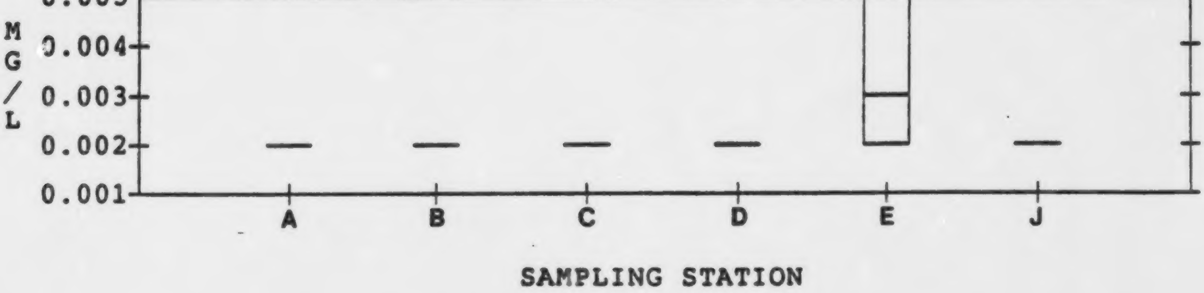


Figure 5.34
EXTRACTABLE IRON IN ST CROIX RIVER
1986 GRAB SAMPLING DATA

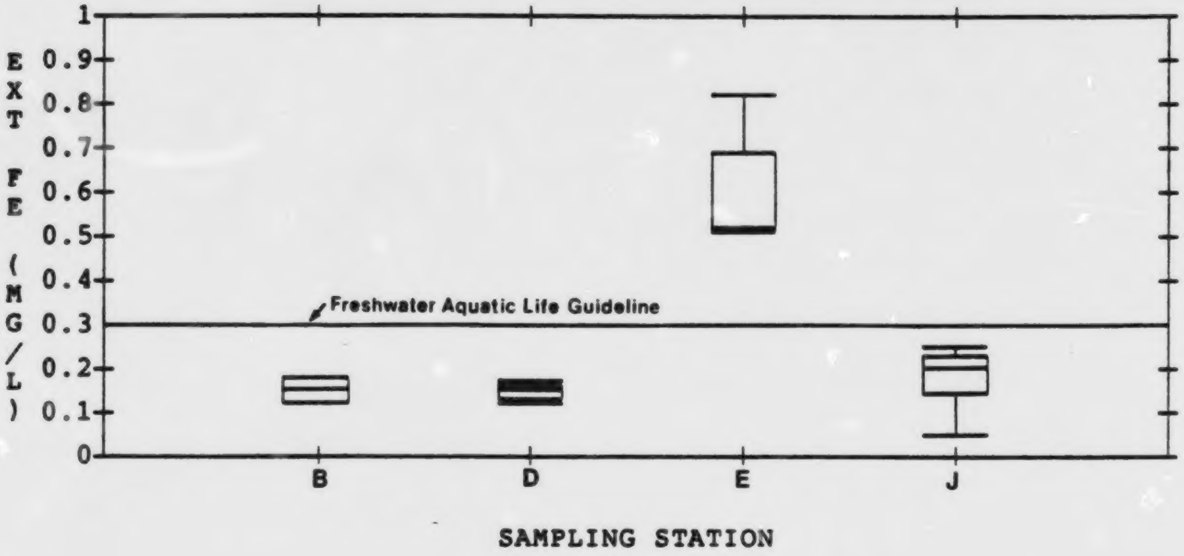
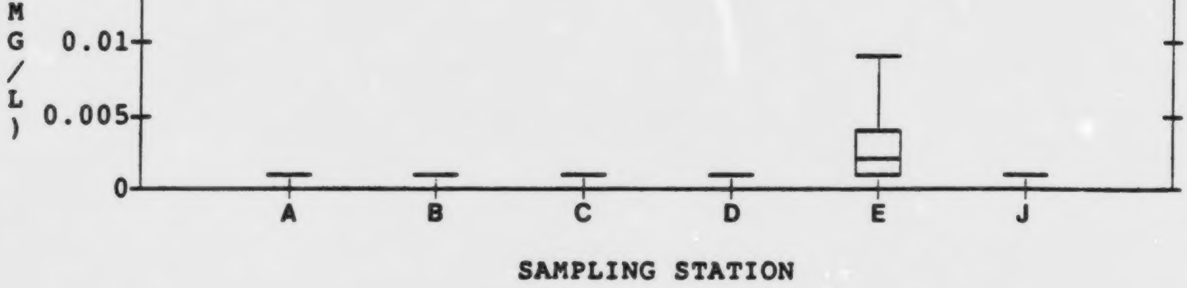


Figure 5.35
EXTRACTABLE LEAD (MG/L) IN ST CROIX RIVER
1986 GRAB SAMPLING DATA



The guidelines for lead and mercury are for 0.03 mg/l and 0.1 mg/l respectively, and Figures 5.35 and 5.36 show that these were not exceeded in 1986. Values for both parameters were below the detection limits except for Woodland samples. At Woodland, lead values ranged from the detection limit of .002 mg/l to 0.008 mg/l. In only one instance was there a value for mercury (0.03 mg/l) that was slightly above the detection limit of 0.02 mg/l.

Figure 5.37 shows that all sites above Woodland had suspended solids levels less than the detection limit of 10 mg/l. Values at Woodland ranged from 39 to 142 mg/l with a median of 55 mg/l. At Milltown, values were below the detection limit.

Another approach taken in the investigation of water quality below Woodland involved a survey of benthic invertebrate populations at downstream stations (Adamus, 1980). Of the six downstream stations surveyed, only one (Station 3, Grass Island, U.S. side) was found to be significantly stressed, and the Canadian side of the river was markedly less stressed. Benthic productivity was good below Woodland, and no significant differences in community structure between upstream and downstream sites was apparent. This led to the conclusion that adequate feeding conditions existed for the several game fish which inhabit this stretch of the river. These findings are a further indication that water quality below Woodland is presently at acceptable levels.

From September 4, 1983 to September 18, 1983, the Georgia-Pacific Mill was shut down for routine maintenance, which provided an opportunity to investigate the response of the St. Croix River to reduced and varying effluent loads.

Although the mill was inoperative for fourteen days, effluent discharge never ceased completely. Effluent discharges were reduced from 94,000 m^3/l (24.8 MGD) on September 1 to 10,220 m^3/s (2.7 MGD) on September 7, and then reached normal operational levels by September 20. A similar reduction in river discharge was also recorded (Howell, 1984).

Figure 5.38 presents the variation in selected major ion concentration over time. The major ions which showed the greatest response were sodium and choride, and to a lesser extent, sulphate and total alkalinity. These ions are used extensively in the Kraft process and thus are found in high concentrations in the effluent discharge (Howell and Lockerbie,

Figure 5.36
EXTRACTABLE MERCURY (UG/L) IN ST CROIX RIVER
1986 GRAB SAMPLING DATA

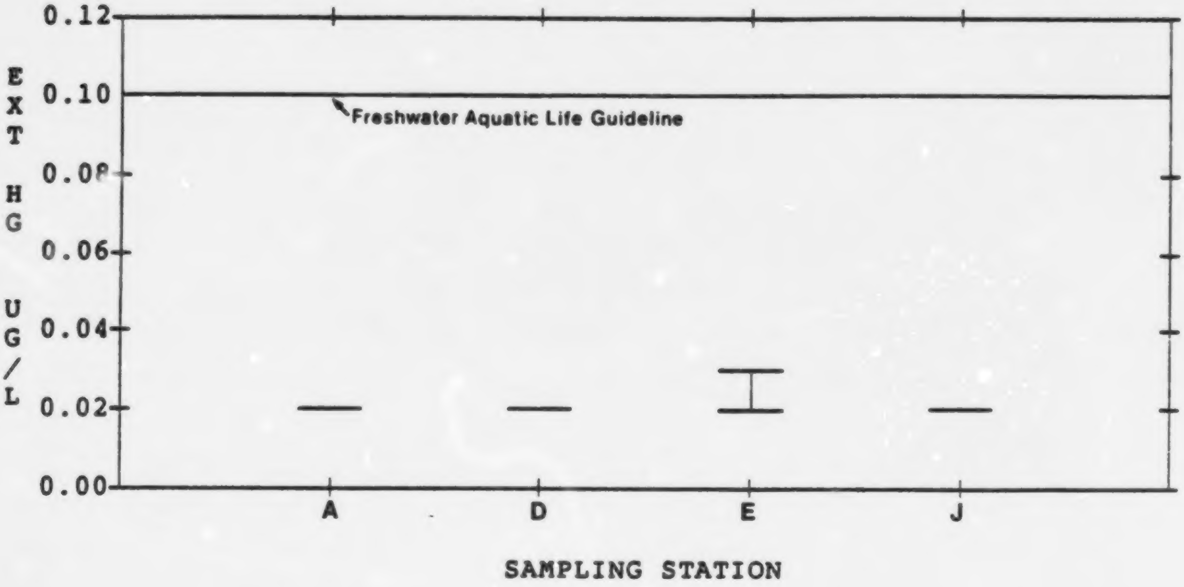
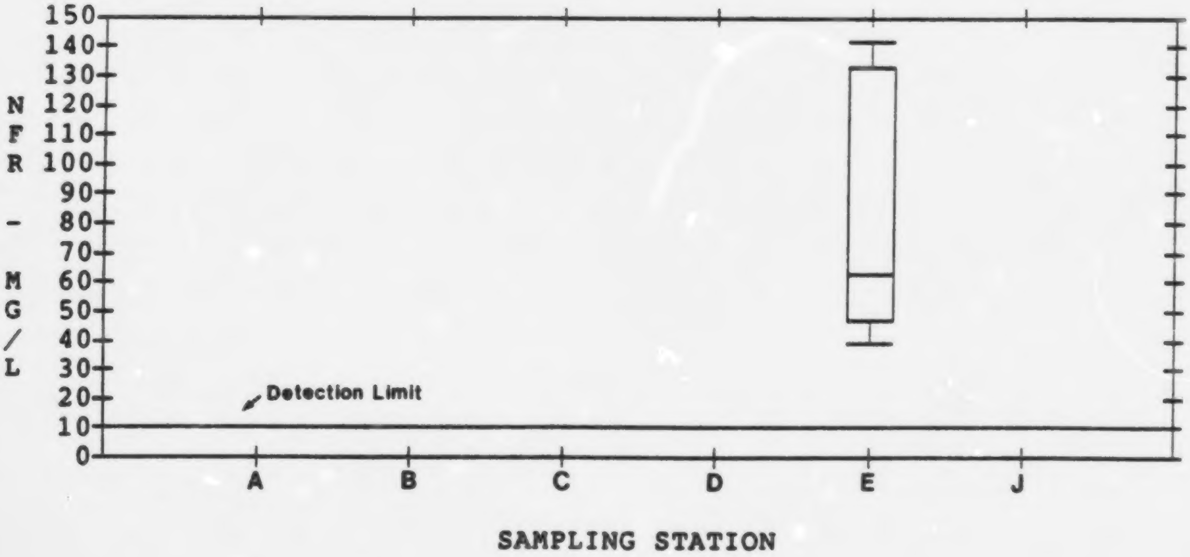


Figure 5.37
NON-FILTERABLE RESIDUE (MG/L) IN ST CROIX RIVER
1986 GRAB SAMPLING DATA



1983a). As would be expected, the specific conductance, plotted in Figure 5.39, also shows a significant response to the mill shut-down.

Howell (1984) determined by a series of linear regressions that, although the data suggest that there is a rapid in-river response at Milltown to a reduction in effluent loading, the best relationship was found for a 24-hour lag period.

It was expected that a mill shut-down would elicit an increase in dissolved oxygen at the Milltown site. However, at the AWQM, there was no significant change in either the concentration or saturation of dissolved oxygen over the study period. It is possible that this lack of apparent response is a consequence of both reduced river discharge and effluent discharge during the study period (Howell, 1984).

In order to better understand the oxygen regime of the St. Croix River, predictive oxygen models have been developed by Boutot and Clair (1981), and Boutot and Howell (1985). These models use BOD loadings, water temperature and river discharge rate to estimate oxygen concentrations at numerous nodal points between Woodland and Milltown. Although these models make accurate oxygen predictions, they are too complex to be used to make short term flow adjustments in order to avoid oxygen depletion.

The results of regression, based on a series of grab samples (n = 128) collected at Milltown between the years 1979 to 1981, indicate that there is a good linear relationship between specific conductance, water temperature and percent saturation of dissolved oxygen, having a multiple correlation coefficient of 0.80 (Howell, 1984).

Using this multiple regression equation, a nomographic method was developed which predicts dissolved oxygen saturation from specific conductance and water temperature. Comparison of predicted Milltown oxygen saturation at Milltown with actual AWQM values indicates that the linear model generally predicts slightly lower values than observed, which is desirable as they will correct for possible prediction and sampling errors. The nomograph was further modified to incorporate the influence of discharge (Howell, 1987). The nomograph clearly indicates that, at the present minimum flow requirement of 21.2 cms (750 cfs), the St. Croix River would be expected to be always in compliance with the 60% dissolved oxygen saturation objective at water temperatures that have

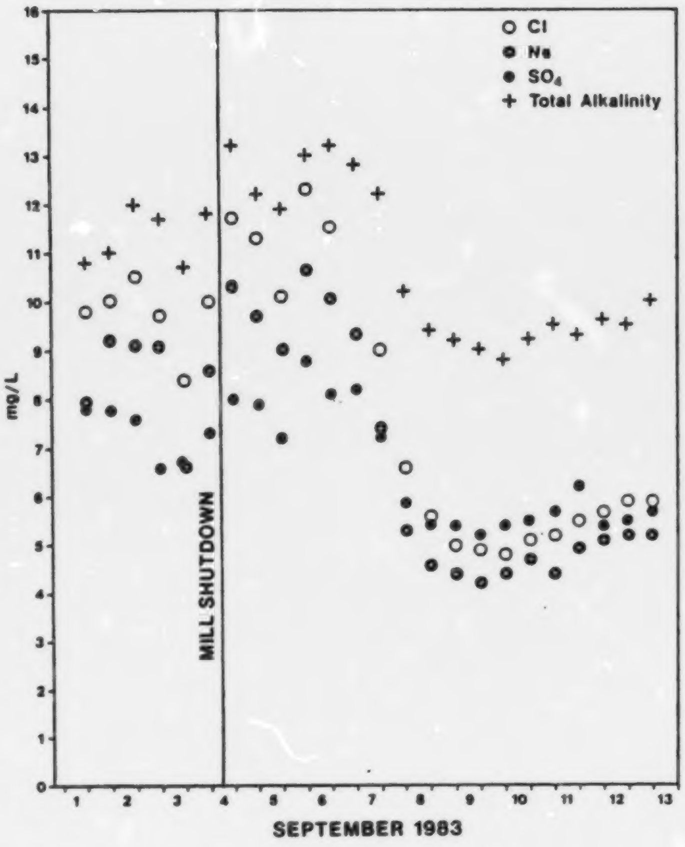


Figure 5.38 Variation in Selected Major Ion Concentrations Over a 13 Day Period

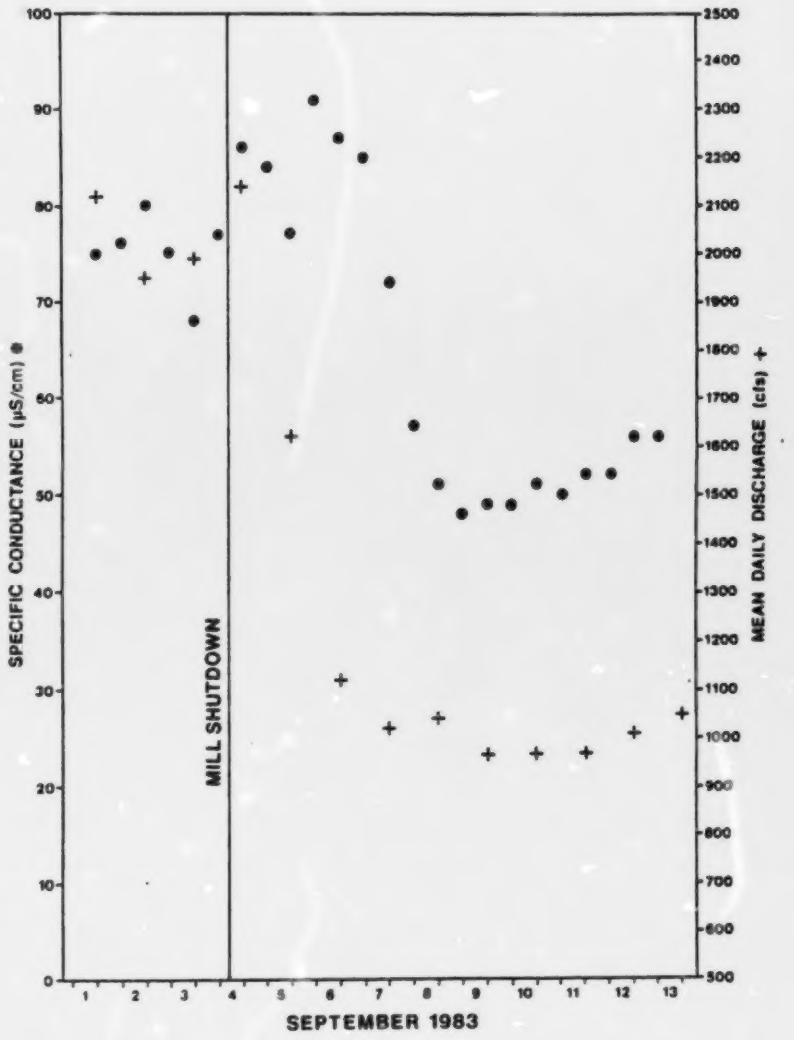


Figure 5.39 Variation in Specific Conductance and Mean Daily Discharge over a 13 Day Period

occurred during the period of record. Furthermore, any slight alterations of the minimum discharge requirement, such as an increase to 26.9 cms (950 cfs), would appear to have only slight effects on the dissolved oxygen saturation values.

5.5.2 FISHERIES

Water Quality is an integral factor in maintaining or developing a viable fisheries resource in the St. Croix River Basin.

Water quality above Woodland has been discussed above in detail and has been shown that water quality reflected background conditions and therefore should have no adverse effects on fish populations.

However, the 14 km section of river between Woodland and Milltown is defined as a water quality limited segment (Howell and Lockerbie, 1984). The water quality of this reach has been previously discussed above. As shown in Figures 5.17 and 5.18, mean dissolved oxygen levels in 1975 and 1976 often dropped to 2 to 3 mg/l with minimum readings of 0.5 and 1.5 mg/l, resulting in fish kills. In 1978, the I.J.C. Advisory Board on Pollution Control established water quality objectives for dissolved oxygen (5.0 mg/l and 60% saturation) with particular reference to the passage of Atlantic salmon (Salmo salar). Since 1977, mean dissolved oxygen levels have exceeded the water quality objective except for episodal events of high effluent loading combined with low flow which have resulted in depressed dissolved oxygen readings. A major fish kill occurred in 1980 when an electrical malfunction caused reduced flow and a reduction in dissolved oxygen to 0.5 mg/l.

Since this incident in 1980, minimum dissolved oxygen levels have exceeded the water quality objective. In 1986, the minimum dissolved oxygen was 6.5 mg/l.

Since the stocking program in 1980, salmon returning to the system have increased from 79 in 1981 to 320 plus in 1986. Alewives counts have also shown impressive increases from 170,000 in 1981 to 2,000,000 in 1986.

A considerable soft-shell clam resource exists in the St. Croix River estuary, however, the river has been closed to harvesting due to fecal contamination.

In a 1982 bacteriological survey of the St. Croix River, data indicated the river portion was subjected to fecal pollution from the discharge of inadequately treated sewage from St. Stephen, Calais, Milltown, Ocean Maid Foods and cottages along the shore. Oak Bay and Waweig River were subjected to intermittent fecal contamination from surface runoff and direct discharge from dwellings along the shore (Menon et al, 1982).

Although the 1982 survey indicated considerable improvement in fecal coliform levels as compared to the 1972 survey, these areas exceeded the bacteriological criteria for harvesting of shellfish. The bacteriological water quality in the eastern shore of the lower St. Croix River from Wiley's Corner to Joe's Point was satisfactory for the harvesting of shellfish (Menon et al, 1982).

5.5.3 AGRICULTURE

Agricultural activities in the St. Croix River Basin do not pose a serious threat to water quality and water quantity in the basin. It is likely only that blueberries will increase in importance as a cash crop in the study area as a spin-off from the nearby commercial wild blueberry industry. The use of pesticides and fertilizers has the potential for affecting water quality but available data do not indicate the presence of a problem.

To obtain an insight into the recent use of pesticides, focus shifted to Saint David Parish, N.B. This contains a relatively large amount of agricultural land, mainly commercial blueberries. The following data in Table 5.6, on application of Guthion, were provided by K. Kiely, Environment Canada. The only reported pesticide used is Guthion, applied by aircraft at a rate of 0.421 l/ha (6 oz/acre). The target of Guthion is the blueberry maggot.

From this specific case, it is evident that the type of pesticide used, the area of application and the amount applied is limited, in what represents the major agriculture area on the Canadian portion of the basin. Two other factors, the reported short lifespan of the organophosphate Guthion and the arsenical compounds it replaced are indications of a limited potential cause for concern.

TABLE 5.6

APPLICATION OF GUTHION

DATE	AREA (ha)	AMOUNT OF GUTHION (litres)
1986	36	15
1985	22	9
1984	28	12
1983	22	9
1982	28	12
1981	22	9
1980	28	12

Fertilizers also play an important role in productivity, and there is some discussion in the literature on accelerated eutrophication caused by excessive nutrient levels. Water quality data indicates that the levels of nitrates and phosphates fall within acceptable guidelines. The monitoring data show that the amount of runoff carrying fertilizer reaching the St. Croix River is not a problem at or above the water sampling station at Kellyland. Another indicator of a limited amount of soil erosion and resulting river sedimentation is turbidity. Since the river water above Woodland generally meets water quality guidelines, added support is provided to the conclusion that agricultural pollution is not an issue in the St. Croix River Basin. The lack of non-point agricultural pollution sources mapped for the Washington County Soil and Water Conservation District graphically illustrates the above conclusion.

A main problem related to agricultural chemicals noted in a Washington County Soil and Water Conservation District report is container disposal. Education directed to the proper disposal techniques is considered the main solution to this problem (WCS&WCD 1977).

It is possible that more chemicals may enter the St. Croix River during periods of high water levels from the large blueberry barrens to the south and west of the basin, than originate within the basin. Such a conduit might be Meddybemps Lake which can flow into the St. Croix River, depending on the lake level, although normally, it flows south to Dennys River.

Other chemical applications are related to forest protection from the Spruce Budworm (Choristoneura fumiferana) which has had a considerable impact on the region's spruce-fir stands. Spraying in the basin began in 1974 and continued annually from 1977 until 1985 (except for 1981). Mexacarbate, carbaryl, trichlorton and acephate were primarily used until Bacillus thuringiensis (Bt) was applied more often after 1978 (QLF-ACE, 1986).

SECTION SIX
GROUNDWATER HYDROLOGY

6.0 GROUNDWATER HYDROLOGY

6.1 INTRODUCTION

Groundwater is an important natural resource used by 64% of New Brunswick's population (Hess, 1981) and 57% of Maine's population (Solley, Chase and Mann, 1983). Moreover, groundwater accounts for 98% of rural water supplies in Maine and 90% in New Brunswick. The industrial and agricultural sectors are significant users of self-supplied groundwater (Table 6.1). The distribution of major groundwater withdrawals is, however, associated with population centres.

TABLE 6.1

ESTIMATED GROUNDWATER USE IN NEW BRUNSWICK AND MAINE

	Annual Groundwater	Percentage of Use by Sector			
	Use (1000 m^3)	Municipal	Rural	Agricultural*	Industrial*
New Brunswick	75,409	42	29	4	25
Maine	110,522	25	32	1.1	42

* Agricultural - Includes livestock and irrigation
* Industrial - Self-supplied water only, includes fish enhancement

Notes: 1. Withdrawal data for New Brunswick from Hess, J.P., 1981.
2. Withdrawal data for Maine from Solley, Chase and Mann, 1983.
3. Data may not add due to rounding.

6.2 OCCURRENCE AND MOVEMENT OF GROUNDWATER

Hydrogeology encompasses the recharge, movement and discharge of water through the earth's crust. Factors determining the hydrogeological regime include climate, topography and geology. Precipitation assures a renewable source for underground water; topography provides the divides and basins for the collection of surface runoff, and the elevation differences needed for movement of underground water under the influence of gravity; and geology provides the medium for the storage and transmission of groundwater.

The physiography and climate of the St. Croix River Basin is described in Section 2.0. Generally, precipitation is more than sufficient to replenish the water pumped from aquifers in the basin. Mean annual precipitation for the period from 1951 through 1980 ranged between 1050 mm (29 in.) in the western portion of the basin to 1250 mm (34 in.)

in eastern areas (Figure 2.2). In most instances, however, only 10 to 20% of the precipitation infiltrates the soil to recharge aquifers; the remainder runs off into streams and lakes, or returns to the atmosphere (Caswell, 1979).

The distribution of groundwater within the geologic system is dependent upon the physical properties of geologic materials occurring at or near the earth's surface. Groundwater, which moves only centimetres per day, travels through soils and rocks and eventually discharges into springs, lakes, rivers and the ocean. The components of the groundwater system includes all gradations of geologic materials from aquifers which may store and yield appreciable quantities of water to wells and aquitards and aquicludes (or confining beds) that effectively retard or prevent appreciable movement of water.

Figure 6.1 shows some of the common types of groundwater movements that occur in the glaciated sediments and fractured bedrock of the St. Croix River Basin. Unconfined aquifers are usually found in recharge areas where the percolation of water into the ground gradually fills small voids and spaces saturating the permeable material. The upper limit of the saturated zone where water occurs under pressure equal to atmosphere pressure marks the water table. Elsewhere, except under perched water-table conditions, aquifers are confined beneath less permeable stratigraphic limits. The water level in a well penetrating such an aquifer will correspond to the pressure in the aquifer at the well screen.

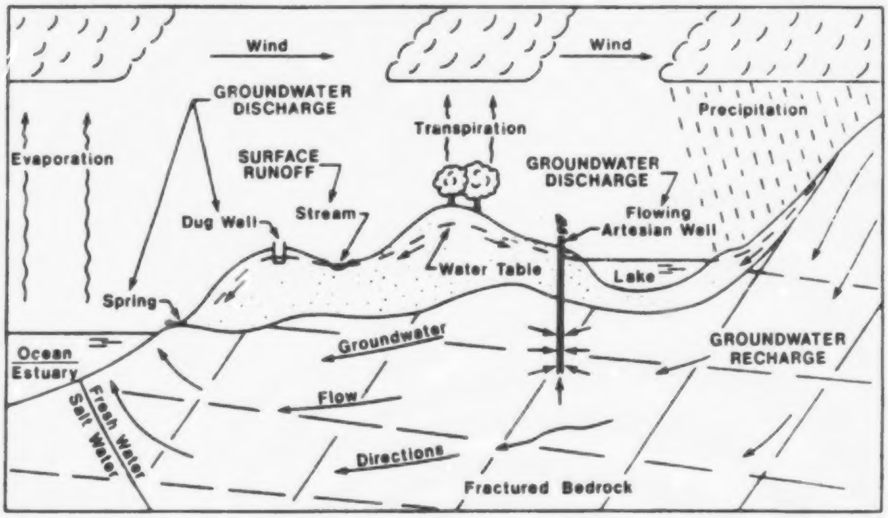

Wind
Wind
GROUNDWATER DISCHARGE
Transpiration
Precipitation
Evaporation
SURFACE RUNOFF
GROUNDWATER DISCHARGE
Dug Well
Stream
Flowing Artesian Well
Water Table
Lake
Spring
Groundwater
GROUNDWATER RECHARGE
Ocean
Estuary
Fresh Water
Salt Water
Flow
Directions
Fractured Bedrock

Figure 6.1 Paths of Groundwater Movement

Water everywhere in the subsurface is in motion along well defined flow paths. The factors that determine the hydraulic-head distribution, and therefore the flow path, are topography and permeability distribution. Usually, in any one basin, several flow systems, local, intermediate and regional, can be distinguished. Moreover, in any one flow system, groundwaters of differing ages and chemical quality will be present. Waters near the recharge zone will be younger since they will have been residing underground for a shorter time than waters in the same flow system near the discharge point. Throughout its underground residence, water is continuously in contact with the surrounding rock and soil matrix, interacting with it both physically and chemically. As chemical aging occurs, it results in typical composition sequences. For example, carbonate, calcium and magnesium, are usually prominent ions in young water, but, on aging, the carbonate is usually replaced by sulphate and chloride, and the calcium and magnesium by sodium.

6.3 PRINCIPAL AQUIFERS

Two principal aquifers occur in the St. Croix River Basin; bedrock composed of igneous and metamorphic rocks, and unconsolidated glacial deposits. A description of bedrock and surficial materials and their occurrence within the basin is presented in Sections 2.3 and 2.4, respectively. The hydrogeological characteristics of the bedrock and the unconsolidated glacial aquifers are described below and in Table 6.2, and their areal distribution is shown in Figure 6.2.

6.3.1 THE BEDROCK AQUIFER

Groundwater availability and yields from the bedrock aquifer is dependent upon fracture availability and size. Four major mountain-building events have folded, faulted, and highly fractured much of the bedrock in the basin. For these reasons, the hydraulic properties of the crystalline bedrock in the St. Croix River Basin are similar, and therefore are considered to be a single aquifer.

Maloney and Cowing (1985) reported common well yields from crystalline bedrock in Maine ranging between 0.13 and 0.63 l/s (2-10 U.S. gal./min.), however, some well yields may exceed 32 l/s (500 U.S. gal./min.) (Table 6.2). Water well records from the St. Croix River Basin in New Brunswick show average minimum/maximum yields ranging

TABLE 6.2

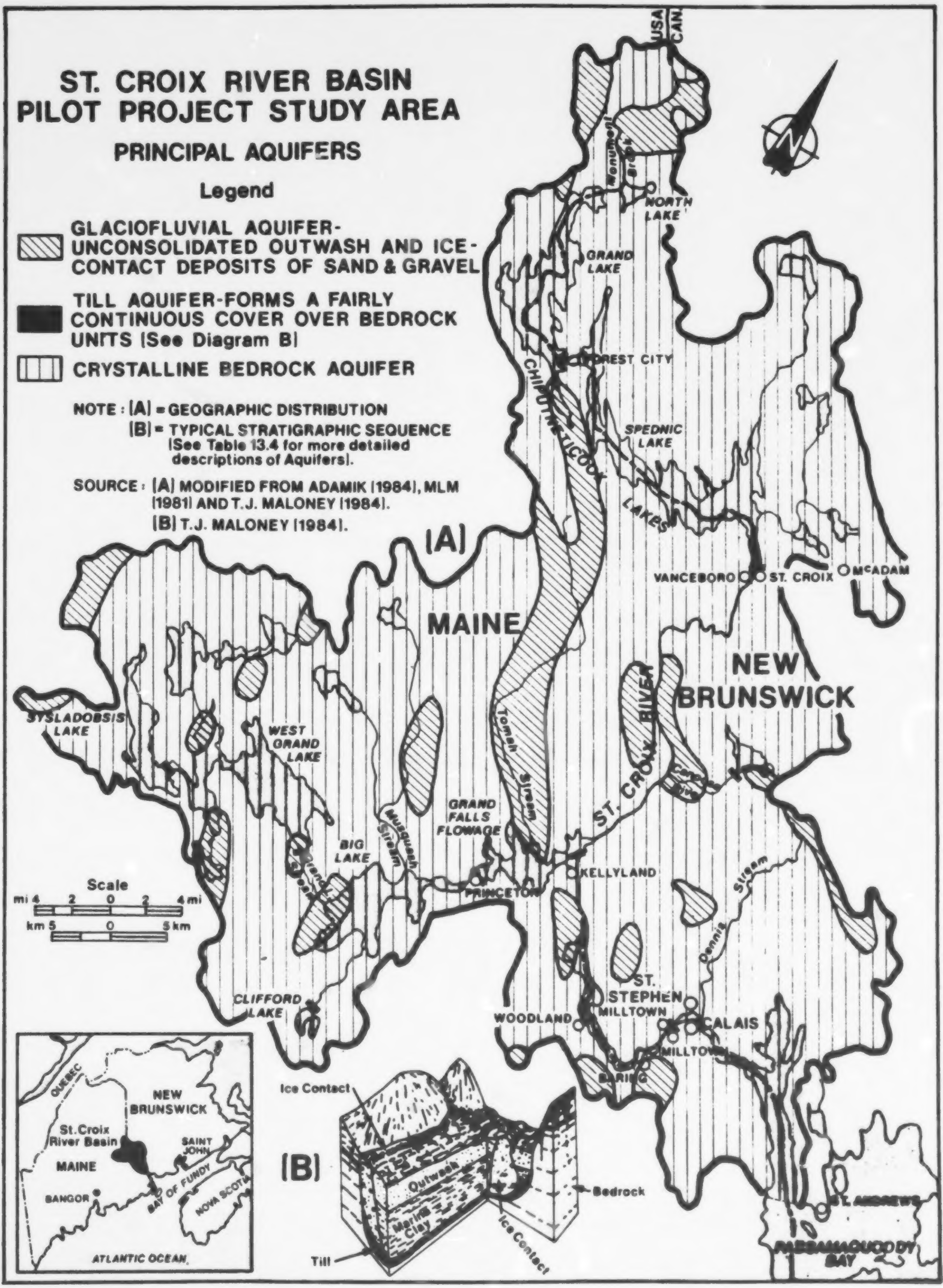
AQUIFER AND WELL CHARACTERISTICS OF CRYSTALLINE BEDROCK AND SURFICIAL DEPOSITS IN NEW BRUNSWICK AND MAINE

Aquifer Name and Description	Well Characteristics			Remarks
	Depth (m/s)	Yield (l/s)		
	Common Range	Common Range	May exceed	
Crystalline bedrock aquifer: This unit consists of a variety of igneous and metamorphic rocks. Igneous rocks include granite, gabbro, diorite, granodiorite, and pegmatite and metamorphic rocks include schist, gneiss, quartzite, slate, and argillite. Locally confined at depth.	N.B. 1.4-203 Me. 6.0-245	0.1-1.0 0.13-0.63	23 32	Crystalline bedrock dense and relatively impermeable and contains recoverable water in secondary openings such as joints, fractures, and bedding or cleavage planes. Chemical quality of water good for most uses. Concentrations of iron and manganese exceeding national drinking water regulations found in some wells. Large concentrations of radon 222 have been found in the water, primarily from wells finished in granite, pegmatite, and metamorphosed rocks in Maine.
Glaciofluvial Aquifers				
Ice-contact deposits: Deposits consist of well to poorly stratified deposits of sand, gravel, and cobbles, with some silt clay, and boulders. Because the deposits were laid down under a variety of conditions, the variation in texture, sorting and internal structure is great. Deposits overlie bedrock or till. May be overlain by younger unconsolidated units, principally marine deposits. Generally unconfined.	N.B.* 10-60 Me. 11-43	>40 3.2-63	115 190	Generally, best source of large supplies of groundwater. Yields depend upon thickness sorting, and grain size of deposit. Better yields obtained where deposits are in hydraulic continuity with adjacent body of surface water for recharge. Associated landforms include kames, eskers, and crevasse fillings. Quality of water generally good for most uses. In some localities, large concentrations of iron and manganese severe enough to limit use without treatment. Because of permeability and typically shallow water table, these deposits susceptible to contamination.
Outwash Deposits: Stratified sand and gravel deposits in valley trains, outwash plains, or deltas. Percentage of gravel is greatest near ice-contact deposits and decreases seaward. Deposits contain some silt, clay, and cobbles. May overlie or interfinger with marine or glacial lake deposits. Generally unconfined.	N.B. 10-30 Me. 11-37	<76 0.63-6.3	230 126	Yield depends upon thickness and grain size of deposits; better yields where deposits are in hydraulic continuity with adjacent body of surface water for recharge. Water generally of good quality for most uses, but, in northern Maine, moderately hard. Large concentrations of iron and manganese commonly reported.
Till Aquifer: Till is a heterogeneous mixture of clay, silt, gravel, cobbles and boulders deposited directly from glacial ice. Forms a fairly continuous cover of varying thickness over bedrock in upland areas and occurs beneath younger deposits and above bedrock in some of the lowland areas. Generally unconfined.	N.B. 3-9 Me. 3-9	<0.06 <0.06	1.3 1.3	Source of water for numerous dug or drilled domestic wells. Generally low permeability Yields water to wells very slowly. Wells likely to become dry in late summer when water tables are low. Quality of water generally good. Excessive iron concentrations may be a problem.

Source: Reports of the Geological Surveys of Canada and the U.S.,New Brunswick Department of Mines and Energy, Maine Geological Survey, and the New Brunswick Department of the Environment.

Note*. Best approximation based on literature.

N.B. denotes New Brunswick; Me. denotes Maine; m is metres; l/s is litres/second



ST. CROIX RIVER BASIN
PILOT PROJECT STUDY AREA

PRINCIPAL AQUIFERS

Legend

▨ GLACIOFLUVIAL AQUIFER-UNCONSOLIDATED OUTWASH AND ICE-CONTACT DEPOSITS OF SAND & GRAVEL

■ TILL AQUIFER-FORMS A FAIRLY CONTINUOUS COVER OVER BEDROCK UNITS [See Diagram B]

▥ CRYSTALLINE BEDROCK AQUIFER

NOTE : [A] = GEOGRAPHIC DISTRIBUTION
[B] = TYPICAL STRATIGRAPHIC SEQUENCE [See Table 13.4 for more detailed descriptions of Aquifers].

SOURCE : [A] MODIFIED FROM ADAMIK [1984], MLM [1981] AND T.J. MALONEY [1984].
[B] T.J. MALONEY [1984].

[A]
USA
CAN.
Monument Brook
NORTH LAKE
GRAND LAKE
FOREST CITY
CHIPUTNETICOOK
SPEDNIC LAKE
LAKES
VANCEBORO
ST. CROIX
McADAM
MAINE
NEW BRUNSWICK
SYSLADOBSIS LAKE
WEST GRAND LAKE
Tomah Stream
ST. CROIX RIVER
GRAND FALLS FLOWAGE
Musquash Stream
BIG LAKE
PRINCETON
KELLYLAND
Dennis Stream
ST. STEPHEN
MILLTOWN
WOODLAND
CALAIS
MILLTOWN
BARING
CLIFFORD LAKE
ST. ANDREWS
PASSAMAQUODDY BAY
Scale
mi 4 2 0 2 4 mi
km 5 0 5 km
QUEBEC
NEW BRUNSWICK
St.Croix River Basin
SAINT JOHN
MAINE
BANGOR
BAY OF FUNDY
NOVA SCOTIA
ATLANTIC OCEAN
[B]
Ice Contact
Outwash
Marine Clay
Till
Ice Contact
Bedrock

Figure 6.2

between 0.15 and 1.9 l/s for 317 samples. The highest reported yield from a well 91 metres deep (300 ft.) was 23 l/s (365 U.S. gal./min.).

Moreover, Caswell (1979) reported that about 86% of Maine's bedrock wells yield at least 0.13 l/s (2 U.S. gpm) and 30% yielding more than 0.63 l/s (10 U.S. gpm). Water well data from the St. Croix River Basin in New Brunswick show 85% of drilled wells with yields in excess of 0.13 l/s, and 38% yielded more than 0.63 l/s (Figure 6.3 A and B). A 0.24 l/s (2 U.S. gpm) well, 46 m(150 ft.) deep, is an adequate water supply for a typical household.

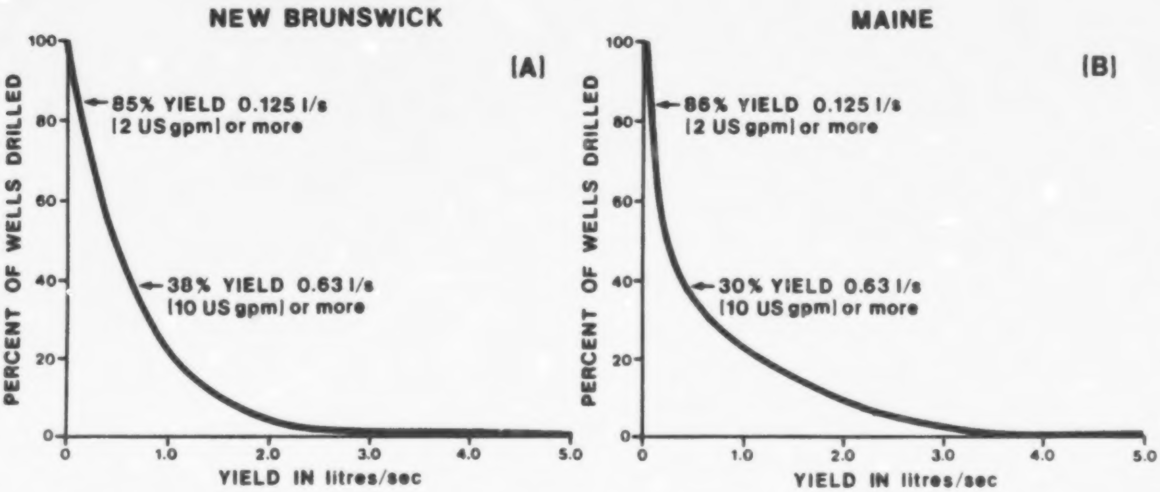


Figure 6.3 Yield of Bedrock Wells in New Brunswick and Maine
(Figure B - Modified from Caswell, 1979)

Caswell (1979) made several practical observations about the frequency of fractures in crystalline bedrock in Maine, and their relation to water well yields. Only one or two water-bearing fractures are interseated between 15 and about 180 m (50 to 600 ft.) (Figure 6.4). However, the size of individual fractures appears to be hydrogeologically more important than the number of fractures intersected. Figure 6.5 shows that at least 90% of the wells drilled into fractured bedrock will intersect the first water bearing fracture before reaching 60 m (200 ft.), and 53% of the bedrock wells in Maine will encounter at least two water-bearing fractures.

One of the most characteristic features of crystalline rocks is the general trend of permeability decrease with depth. Fractured crystalline rocks are less permeable at greater depth because stress variations

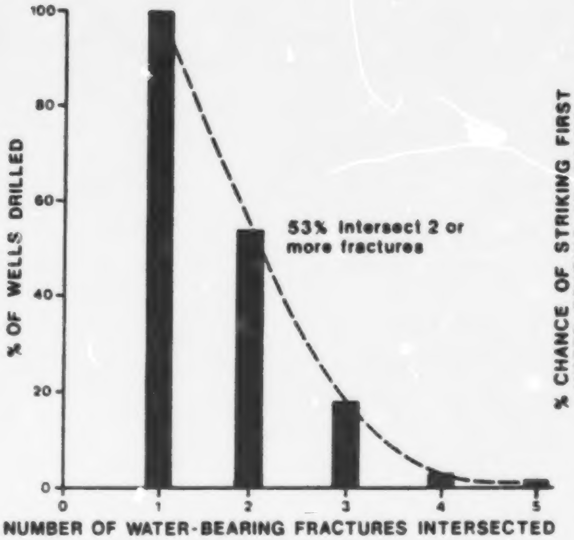


Figure 6.4 Number of Water-Bearing Fractures Intersected by Bedrock Wells (Modified from Caswell, 1979)

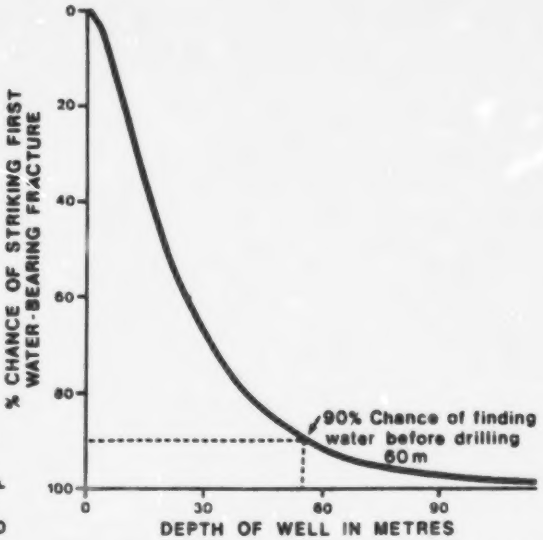


Figure 6.5 Depth in Bedrock to the First Water Bearing Fracture (Modified from Caswell, 1979)

that cause the fractures are larger and occur more frequently near the ground surface. The results of a study of crystalline rocks (granite, gabbro, gneiss, and schist) in North Carolina by LeGrand (1954) quantified the relationship between decreased water yield with depth (Figure 6.6).

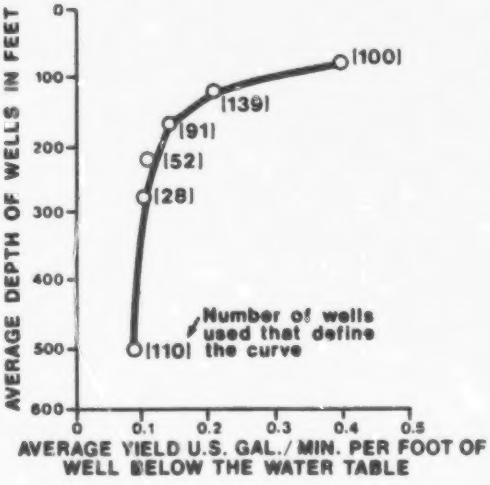


Figure 6.6 Decrease in Well Yields with Depth in Crystalline Rocks (After Legrand, 1954; Davis and De West 1966)

Most bedrock wells in Maine are between 30 to 90 m deep, with a maximum practical depth of about 165 m(550 ft.) (Caswell, 1979). The average depth of wells in the St. Croix River Basin in New Brunswick is about 40 m (135 ft.), however, a broad range of well depths from about 7 to 200 m (23 - 665 ft.) is encountered. Figure 6.7 shows the relationship between the availability of water-bearing fractures and depth in crystalline bedrock in Maine.

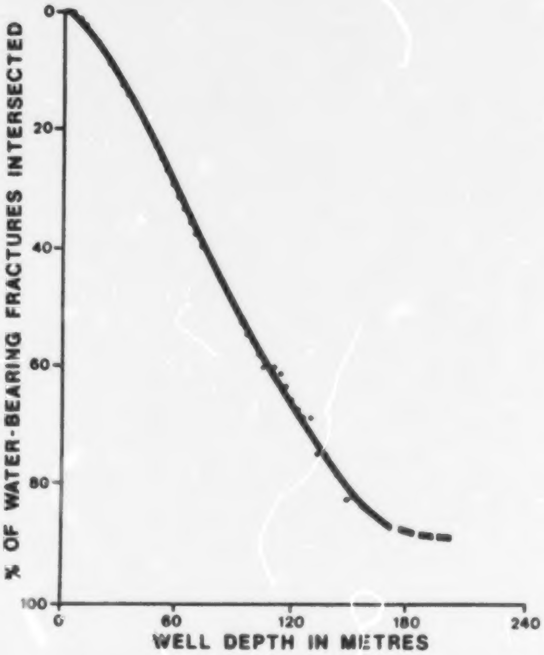


Figure 6.7 Change in the Number of Water-Bearing Fractures with Increasing Depth into Bedrock

The frequency of wells and well yields is also related to topography because many fractures owe their origin to near-surface stresses related directly or indirectly to topographic conditions. LeGrand (1954) also quantified well-yield relations with respect to topography. Figure 6.8 indicates that well yields in crystalline rocks in the North Carolina study area are highest in valleys and broad ravines and lowest at or near the crest of hills. Yields in flat uplands and beneath slopes are between these extremes. In many places, valleys and ravines develop along fault zones. The tendency for fault zones to have greater permeability is the primary factor in the well-yield relationship.

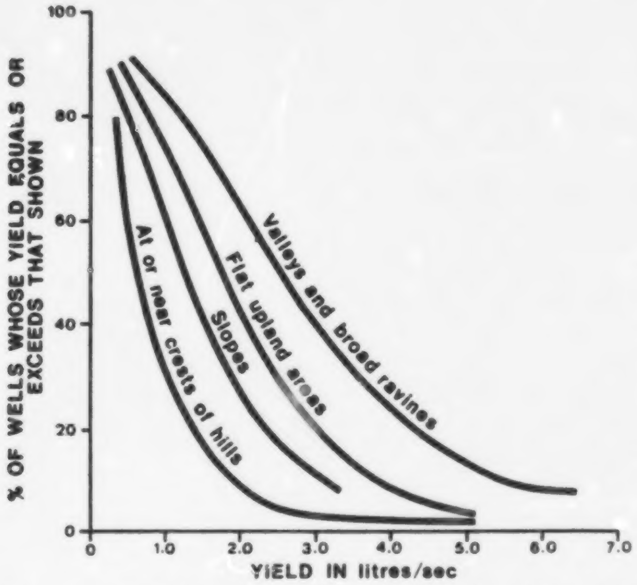


Figure 6.8 Distribution of Well Yields with Respect to Topographic Position (after Legrand 1954; Davis and De Wiest, 1966)

An examination of thousands of bedrock wells in Maine by Caswell (1979) has led to the conclusion that high-yield wells are closely related to major fracture systems. It is possible, therefore, to predict the location of high-yield wells in fractured crystalline rocks, but this is attempted only where no other source of ground or surface water supply is readily available.

6.3.2 EFFECTS OF OVERBURDEN ON BEDROCK YIELDS

Soil of glacial origin forms a patchy cover over bedrock in the St. Croix River Basin. The average thickness of surficial deposits on the New Brunswick side of the basin is about 8 m (25 ft.), a wide range of depths between 0.30 and 90 m (1 to 300 ft.) has been observed from water well logs.

Most of the overburden is clay rich material having poor permeabilities and subsequent poor water transmitting properties. These materials include morainal deposits of till, an unlayered mixture of clay, sand, pebbles and cobbles; and layered marine sediments. The remainder is largely sand and gravel. Unconsolidated glacial deposits serve as aquifers and as an important supply of recharge to underlying bedrock aquifers. Caswell (1979) observed that aquifer thickness and permeability affect the yield of bedrock wells. Bedrock wells overlain by sand/gravel deposits tend to yield more water than wells overlain by till and marine clay deposits (Figure 6.9). The low permeability of till and the near impermeability of marine clay inhibit the downward movement of water into bedrock fractures. Morrissey (1983) observed that about 45% of precipitation recharged a glacial fluvial aquifer in the Androscoggin River Valley in Maine, while only 20% or less of precipitation recharged till.

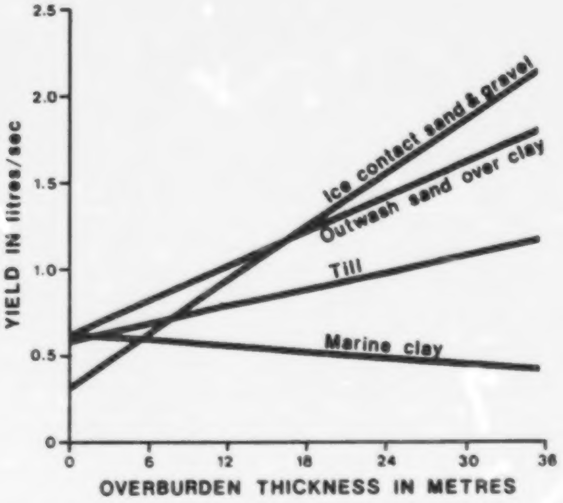


Figure 6.9 Effect of Overburden Type and Thickness on the Yield of Bedrock Wells Drilled into the Underlying Bedrock (Modified from Caswell, 1979)

6.3.3 SURFICIAL AQUIFERS

Glaciofluvial aquifers are composed of unconsolidated outwash and ice-contact deposits. Both deposits consist largely of sand and gravel and, when saturated, are most favourable for development of large water supply wells. However, some deposits at high elevations are drained of water, while others are not highly permeable. The highly productive sand and gravel deposits are those located next to streams and lakes. The unconfined glaciofluvial aquifer servicing the Town of St. Stephen is in direct hydraulic contact with the Dennis Stream, the aquifer yields approximately 7.2 l/s, and the specific capacity is 35 l/s.m.

Outwash deposits were laid down by meltwater streams near the margins of glaciers and many have layers of relatively impermeable marine silt and clay that may confine water within them. Ice contact deposits were formed from sand and gravel which settled from meltwater flowing beneath or through a glacier. Ice contact deposits are often thicker than outwash deposits. These deposits often appear as elongated and discontinuous exposures mostly occupying pre-glacial valleys of the St. Croix River Basin (Figure 6.2).

A large percentage of the inhabitants in the St. Croix River Basin use till as an aquifer because it is pervasive. Expected yields from the till aquifer is at most 1.3 l/s, enough water for domestic, livestock and commercial supply (Maloney and Cowing, 1985). Many of the dug wells in till are shallow and therefore become dry during droughts.

6.4 WATER LEVEL TRENDS AND FLUCTUATIONS

The Province of New Brunswick and the State of Maine do not have continuous water level records to show the effects of climate and water well pumping on groundwater levels in the St. Croix River Basin. However, in New Brunswick and Maine, where water level records are available, there have been no reports of long term declines in groundwater levels. The climate and geology of locations in New Brunswick and Maine with similarities to the St. Croix River Basin indicate that climate (precipitation) affects water level changes in wells more so than pumping stresses, and recharge to wells from precipitation and surface water is usually sifficient to replenish withdrawals (Maloney and Cowing, 1985).

In most situations, the groundwater in bedrock wells is under pressure because overlying solid rock or impermeable glacial sediments tend to confine it. Most groundwater will, therefore, rise from the point where it enters a drilled well to about 6 metres below land surface. Wells of this type are called artesian. Bedrock artesian wells have water levels that fluctuate with changes in air pressure, and changes in tidal levels if they are within about 6 kilometres of the coast. Well B in Figure 6.10 shows a water level rise caused by an air-pressure low that accompanied a storm which dropped 68.5 mm of rain.

Some bedrock wells intersect fractures that are open directly to the land surface. These wells function the same as shallow dug wells and are called water table wells. They show no response to changes in air pressure or tidal levels, but do show significant rapid response to rainfall (Well A, Figure 6.10).

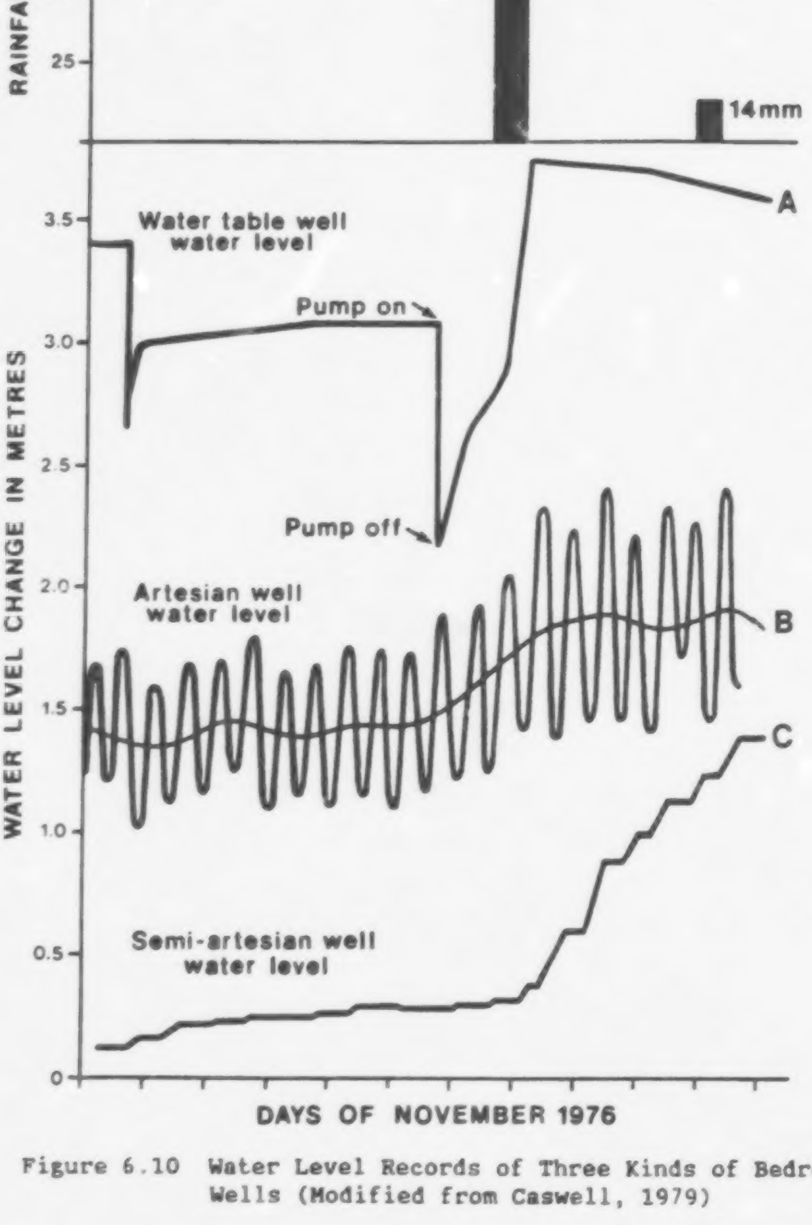


Figure 6.10 Water Level Records of Three Kinds of Bedrock Wells (Modified from Caswell, 1979)

A third type of bedrock well, typically found in glaciated terrain, intersects both confined and unconfined fractures. These semi-artesian bedrock wells show a small response to tides and a moderate response to rainfall (Well C, Figure 6.10).

6.5 GROUNDWATER QUALITY

The quality of groundwater in the St. Croix River Basin is generally good. This is largely because the crystalline bedrock and glacial sediments derived from this bedrock contain few highly soluble minerals, and because significant amounts of rainfall provide a high level of dilution. Most waters are soft to moderately soft.

The more permeable aquifers often have water chemistry which closely approximates that of precipitation or surface water. The valley occupied by the Dennis Stream provides the catchment for the aquifer servicing the Town of St. Stephen. Groundwater and surface water are interdependent in the aquifer at Maxwell Crossing where the town well is located. Water quality in the Maxwell Crossing aquifer is very good (N.B.D.O.E., 1977). Examples of water analyses for the unconfined glaciofluvial aquifer at Maxwell Crossing near St. Stephen and the fractured volcanics in Upper Bayside near St. Andrews are presented in Table 6.3.

Excessive iron is the most common problem, manganese and sulphides are a lesser problem. Elevated concentrations of iron occurs only locally where the bedrock includes iron sulphide rocks (Caswell, 1979). A study of aquifers in southwestern Maine, which are similar to those in the St. Croix River Basin, found an average iron concentration of 1.2 milligrams per litre (mg/l) and an average manganese concentration of 0.42 mg/l. The maximum acceptable concentrations of iron and manganese in water is set at 0.3 mg/l and 0.05 mg/l respectively (Canadian Drinking Water Standards and Objectives, 1978). Although iron and manganese are not considered a health risk, at these levels, below the maximum acceptable concentrations, there is less likelihood of staining laundry and plumbing fixtures, and causing undesireable taste in beverages (CDWSO, 1978).

Wells in some coastal areas have yielded brackish or salty water (Prescott, 1973; Tepper, 1980). A large portion of coastal New Brunswick and Maine in the St. Croix River Basin was flooded by sea water near the close of the last glacial period (Figure 6.11). These salt water wells

TABLE 6.3

HYDROCHEMISTRY OF SELECTED WELLS

		pH	Specific Conductance	Total Alkalinity as $CaCO_3$	Bicarbonate as HCO_3	Sulphate as SO_4	Nitrate-Nitrite as NO_3	Chloride as Cl	Fluoride as F	Total Anions	Total Hardness as $CaCO_3$	Calcium as Ca	Magnesium as Mg	Sodium as Na	Potassium as K	Iron as Fe	Manganese as Mn	Total Cations
1.		6.9	42.8	14							21.0							
	ppm					6.82	0.18	4.79	LTO.1			6.01	1.46	3.0	0.4	0.15	0.04	
	epm				0.28	0.14	0.003	0.14	0.005	0.57		.30	0.12	0.13	0.01	0.008	0.001	0.57
	%epm				49.1	24.6	0.53	24.6	0.9	99.7		52.6	21.1	22.8	1.75	1.4	0.18	99.8
2.		7.0	256	83.6						108								
	ppm					LT1.0	0.113	38.8	LTO.1			33.7	5.83	18.4	1.2	36.5	1.7	
	epm				1.67	0.02	0.002	1.09	0.005	2.79		1.68	0.48	0.80	0.03	1.96	0.06	5.01
	%epm				59.9	0.72	0.07	39.1	0.18	99.7		33.5	9.5	16.0	0.60	39.12	1.2	100

Note: 1. Represents groundwater in glaciofluvial aquifers.

2. Represents groundwater in volcanic rocks.

may intersect relatively isolated fractures, or stagnation zones, in the bedrock aquifer where sea water has been trapped for about 10,000 years (Caswell, 1979).

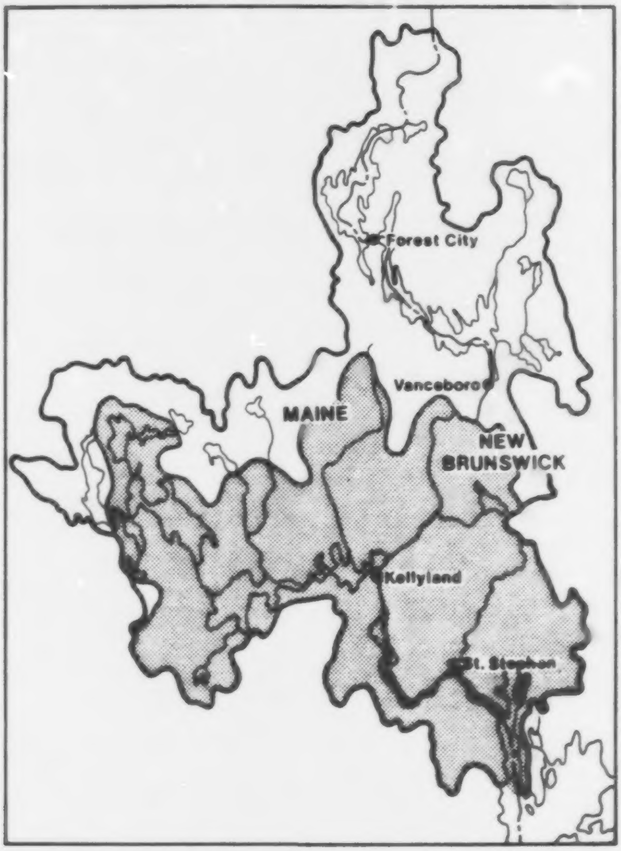


Figure 6.11 Area of the St. Croix River Basin Covered by the Sea at the Close of the Last Glacial Period

A study by the Unversity of Maine at Orono (Hess and others, 1979), found levels of radioactive radon-222 gas in excess of 10,000 pCi/l (370 Bacquerel [BQ]) in water from wells completed in granite, pegmatite and high-grade metamorphic rocks (Maloney and Cowing 1985). The possible health hazard of radon is being investigated.

There is no information on uranium in groundwater in the NAQUADAT system for New Brunswick. However, in 1978, uranium levels in excess of the acceptable limit of 0.02 mg/l suggested by Health and Welfare Canada (1978), were discovered in drilled wells in Harrietsfield, Nova Scotia (about 10 kms south of Halifax).

Subsequently, an extensive groundwater sampling program was initiated in Nova Scotia by the Departments of Health and Environment. During a detailed survey in 1981 in the Harrietsfield area, 44% of 220 drilled wells sampled had uranium in excess of 0.02 mg/l with 7 in excess of 0.10 mg/l. No dug wells had uranium in excess of the limit (MacFarlane, 1982).

MacFarlane, 1982, showed that elevated uranium levels in drilled wells tend to be associated with: (i) thick deposits of silty till overlying granite; (ii) elevated pH levels (7.0 to 8.0); (iii) high radon gas levels; (iv) moderately reducing groundwater environments; and (v) conductance values between 1500 and 450 micro siemens. The uranium is naturally occurring, likely originating from the granite bedrock and the till derived from it.

A possible source is uranium complexed on lake bottom sediments subsequently mobilized in groundwater.

6.6 HUMAN IMPACTS ON GROUNDWATER QUALITY

Groundwater flow patterns determine the movement of pollutants through the subsurface. A source of pollution located at point "A" in Figure 6.12, for example, might contaminate groundwater flowing into the

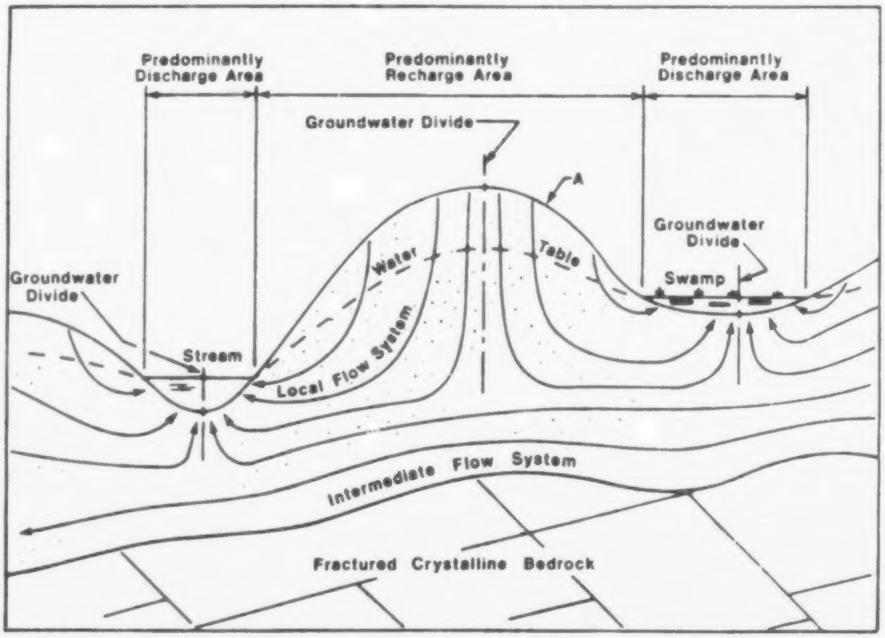

Predominantly Discharge Area
Predominantly Recharge Area
Predominantly Discharge Area
Groundwater Divide
A
Groundwater Divide
Swamp
Groundwater Divide
Water Table
Stream
Local Flow System
Intermediate Flow System
Fractured Crystalline Bedrock

Figure 6.12 Occurrence and Movement of Groundwater Typical of the Sediments and Fractured Bedrock of the St. Croix River Basin (Modified from Caswell, 1979)

adjacent swamp, but would not contaminate groundwater moving into the deeper flow systems. Shallow groundwater flow follows the shape of the land; hills are recharge areas and valleys are discharge areas. Deeper intermediate flow systems within the glacial overburden often follow the shape of the bedrock surface. Flow within the bedrock is controlled in part by (1) the geometry of the fractures; (2) the thickness of the overburden; (3) the land surface topography; and (4) the bedrock surface topography. The overall effect of all these factors is indicated by the relative elevation of static water levels in bedrock artesian wells. Contours of these water level elevations show the potential directions of deep groundwater flow. Groundwater within the bedrock moves theoretically at right angles to the contour lines. The geometry of water bearing fractures alters these theoretical flow directions, but on a regional scale in New Brunswick and Maine, it has been found that groundwater flow in the fractured bedrock is from bedrock highs, where water is recharged, to bedrock lows, where water is discharged.

6.6.1 FUEL STORAGE TANKS

The most serious threat to groundwater quality in both Maine and New Brunswick is the leakage of gasoline and heating oil. Contamination of well water supplies is commonly caused by leaking underground storage tanks.

In Maine, the Department of Environmental Protection reports between 50 to 100 private well contamination cases by fuel oil products each year (Maine EnvironNews 1983). Although three communities have been seriously affected by gasoline contaminants in wells, none are located in the St. Croix Basin. However, over 10,000 litres (2,000 U.S. gallons) of fuel spilled into the St. Croix River from an unidentified Maine border location in late 1984.

The Province of New Brunswick had 71 reported incidents of petroleum contamination in 1983 which led to the contamination of 93 wells. In 1986, petroleum incidents affected 145 wells in New Brunswick (Shaffner, J., 1987 - pers. comm.). Contamination of groundwater and surface water has occurred in McAdam and St. Stephen. For example, in 1977, 100,000 litres (20,000 U.S. gallons) of gasoline leaked from an underground storage tank and reached the St. Croix River at St. Stephen, and at least one well in St. Stephen has been contaminated by an unspecified source of gasoline.

Water well contamination by petroleum products is a chronic problem in McAdam. Most public buildings on the main street have no potable water supplies due to petroleum contamination (Fredericton Planning Region Water Resources Review, 1980). Numerous individual wells have also been contaminated by petroleum products. These wells are located in close proximity to bulk fuel storage areas (pers. comm., J. Shaffner, Environmental Science Branch, NBDMAE, 1987). Investigations are continuing.

6.6.2 SALT STORAGE AND HIGHWAY DE-ICING

The improper storage of road salt is one of the most widespread threats to groundwater quality in New Brunswick and Maine. Stockpiles of salt-treated sand are commonly used by Provincial and State transportation departments, and municipalities for maintenance of roads in winter.

An investigation of the quality and quantity of leachate from highway sand-salt piles in New Brunswick found that, under normal uncovered operating conditions, 18.1 tons or 33% of the original 55 tons of salt used in a 1975/76 experiment was lost. In 1976/77, 25.9 tons, or 57.3% of the original 45 tons of salt used was lost (NBDOE, 1978). There is no information in the literature to suggest that groundwater supplies in the St. Croix Basin are affected by road de-icing sand-salt piles. Since 1984, at least 150 wells in the State of Maine were known to be affected by salt stored in highway maintenance lots, and several additional wells are normally discovered each month. The literature indicates, however, that no major contamination has occurred on the Maine side of the St. Croix Basin.

Remedial measures have been taken, or are being implemented by the Province of New Brunswick and the State of Maine to alleviate the problems associated with sand-salt storage sites.

Sand-salt spreading on highways is also a source of contamination to wells. There is a dearth of information in the literature pertaining to the impact of salt spreading on water well supplies in the St. Croix River Basin. It is expected, however, that highway salt spreading has a lesser impact on water wells than sand-salt storage piles because of a reduction in salt concentrations due to spreading and more efficient drainage along highways than at maintenance depots.

6.6.3 SEPTIC SYSTEMS

Residential sewage from a large number of improperly constructed septic systems have contaminated some private wells in McAdam. Other water problems in the village may be related to the sewage treatment plant which uses some of the old sewer lines. Leaks are believed to be occurring from these old lines which may be causing groundwater contamination (Fredericton Planning Region Water Resources Review, 1980).

McAdam residents have forced a halt to plans for the construction of sewage lagoons. Odours, lowered property values and fear of water contamination were cited as possible problems (Report on a Survey of New Brunswick Newspapers for Water Related Topics, 1979-1984, 1984)

6.6.4 RADIOACTIVE WASTE DISPOSAL

In January 1986, U.S. energy officials announced the selection of 12 possible locations as repositories for high level radioactive waste. By the year 2006, the United States plans to be using one of the sites as an underground storage vault for highly radioactive waste and spent fuel. One site (EN-2) partially infringes upon the headwaters of the St. Croix River Basin. The fear is that, in time, the radioactive waste, to be buried in granite rock thousands of feet below ground, could eventually contaminate ground or surface water in Canada. Possible adverse effects on public and private water supplies and the recreational use of water in the St. Croix Basin are concerns on both sides of the border.

There are at least two complicating factors in the location of Site NE-2. Firstly, Site NE-2 would be housed in a granite complex called the Bottle Lake batholith, which occurs partly within the St. Croix Basin. This batholith is similar to granite bodies in New Brunswick which exhibit various fracturing and jointing phenomenon. Groundwater flow in such earth media, termed fracture flow, is complex and very difficult to define. Secondly, recent seismic activity has been experienced in north central New Brunswick. On January 9, 1982, an earthquake of 5.7 magnitude on the Richter scale was recorded (Brinsmeade, 1983). Of possible significance is the earthquake epicentre which was located in a granite batholith similar to the Bottle Lake batholith. Destruction from an earthquake could significantly change the geohydrological characteristics of the batholith. The facility itself could also be damaged. American officials have assured Canadian officials that nuclear waste repository sites requiring field work in Canada would not be selected.

6.6.5 Other Sources

To date, there have been no reports of groundwater contamination in the St. Croix River Basin due to sludge disposal, solid waste landfills or agricultural practices.

The preceding represents an overview of the data which is presently available. It is, however, likely that all of the potential pollutant sources mentioned, with the exception of nuclear waste, are affecting groundwater to some extent, if only on a local unreported basis. Further, more detailed information from specific data bases, and in consultation with knowledgeable people is required before the local extent of specific problems can be fully identified.

6.7 GROUNDWATER INFORMATION SOURCES FOR NEW BRUNSWICK AND MAINE

The Province of New Brunswick has the ultimate responsibility for the management of their groundwater resources. Provincial agencies with regulatory and management responsibilities in groundwater include the Departments of Municipal Affairs and Environment, Health, Agriculture, and the Fire Marshal's Office. Municipalities also enact relevant by-laws with respect to groundwater.

Of key importance is the New Brunswick Department of Municipal Affairs and Environment which, through their Water Resources Planning Branch, conducts groundwater research and monitoring. Under New Brunswick's Clean Environment Act, regulatory and permit activities are conducted. Groundwater related public information and emergency response is also a responsibility of the provincial government.

The role of Environment Canada is co-operative with that of New Brunswick in preserving and enhancing the groundwater resource for the beneficial uses of this and future generations.

Environment Canada's National Hydrology and Water Research Institutes (NHRI, NWRI) of the Inland Waters Directorate provide a primary source of scientific and technical expertise in areas such as hydrogeological site surveys and contaminant migration modelling. Regionally, both the Inland Waters Directorate and Environmental

Protection provide technical advice on remedial and preventive measures for specific sites and incidences. The Canadian Wildlife Service (CWS) concerns include groundwater quality in wetlands. The Conservation Council of New Brunswick, a private non-profit public interest group, is a leader in publicizing groundwater contamination issues and concerns in the Atlantic Region.

Several Maine State agencies presently have statutory authority over groundwater protection and management. The Department of Conservation, through the Maine Geological Survey and the Land Use Regulation Commission, is responsible for co-ordinating groundwater research, mapping groundwater availability, performing research into permit-related groundwater problems, and regulating activities that impact groundwater in areas where population is sparse.

The Department of Environmental Protection, through its Bureaus of Water, Land, and Oil and Hazardous Materials, is responsible for reviewing and licensing activities that impact groundwater. This Department is also responsible for research into the effects of gasoline leaks and pesticides on groundwater and for groundwater quality assessments and emergency response and cleanup.

The Department of Human Services is involved with groundwater protection and management through its Drinking Water Program, Environmental Health Unit, and Public Health Laboratories. The Department is responsible for reviewing and approving new public water-supply sources, monitoring the quality of existing sources, performing research on groundwater transmitted diseases, and performing water quality analyses of private water supplies.

The Maine Land and Water Resources Council is examining the State's present statutes and regulations, agency programs and manpower, and agency activities pertaining to groundwater in an effort to ensure protection of public health and continued availability of groundwater.

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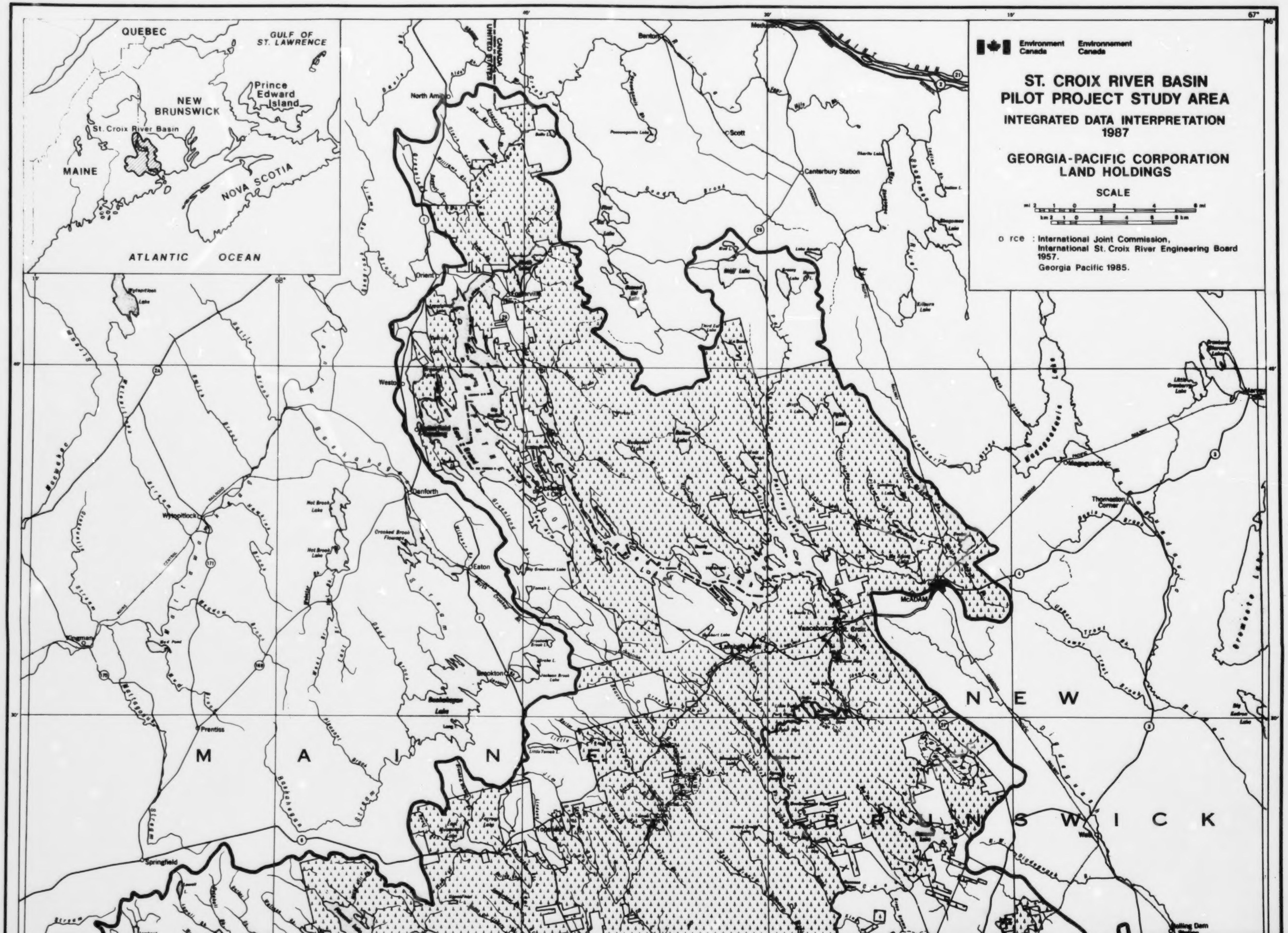
QUEBEC
GULF OF ST. LAWRENCE
Prince Edward Island
NEW BRUNSWICK
St. Croix River Basin
MAINE
NOVA SCOTIA
ATLANTIC OCEAN
CANADA
UNITED STATES
Benton
North Amity
Scott
Canterbury Station
Orient
Weston
Danforth
Wytopitlock
Eaton
Kingman
Brookton
Prentiss
Springfield
McADAM
Vanceboro
St. Croix
Magaguadavic
Thomaston Corner
M A I N E
N E W
B R U N S W I C K
SCALE
mi 2 1 0 2 4 6 mi
km 2 1 0 2 4 6 8 km

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ST. CROIX RIVER BASIN PILOT PROJECT STUDY AREA

INTEGRATED DATA INTERPRETATION
1987

GEORGIA-PACIFIC CORPORATION LAND HOLDINGS

Source : International Joint Commission,
International St. Croix River Engineering Board
1957.
Georgia Pacific 1985.

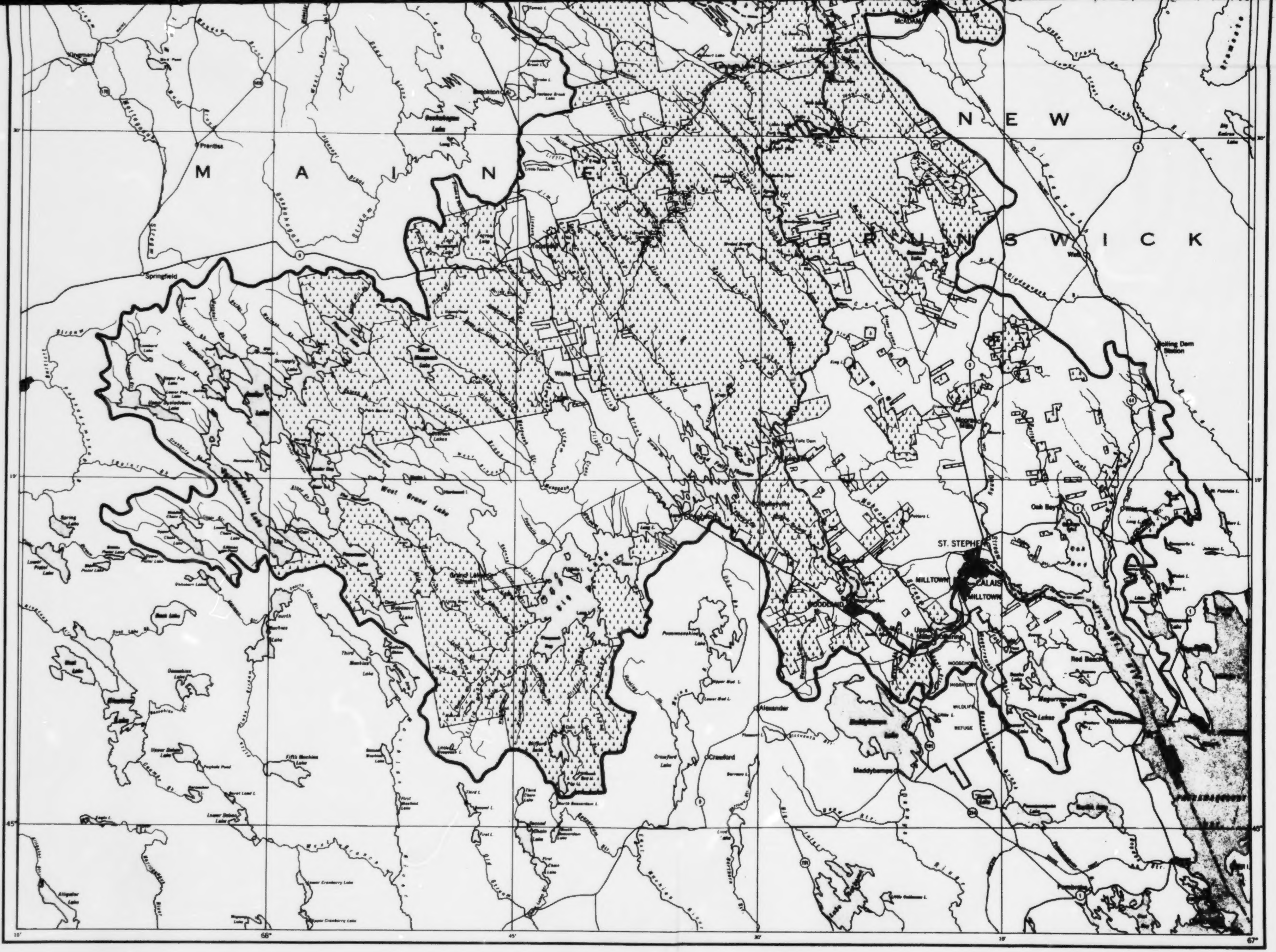
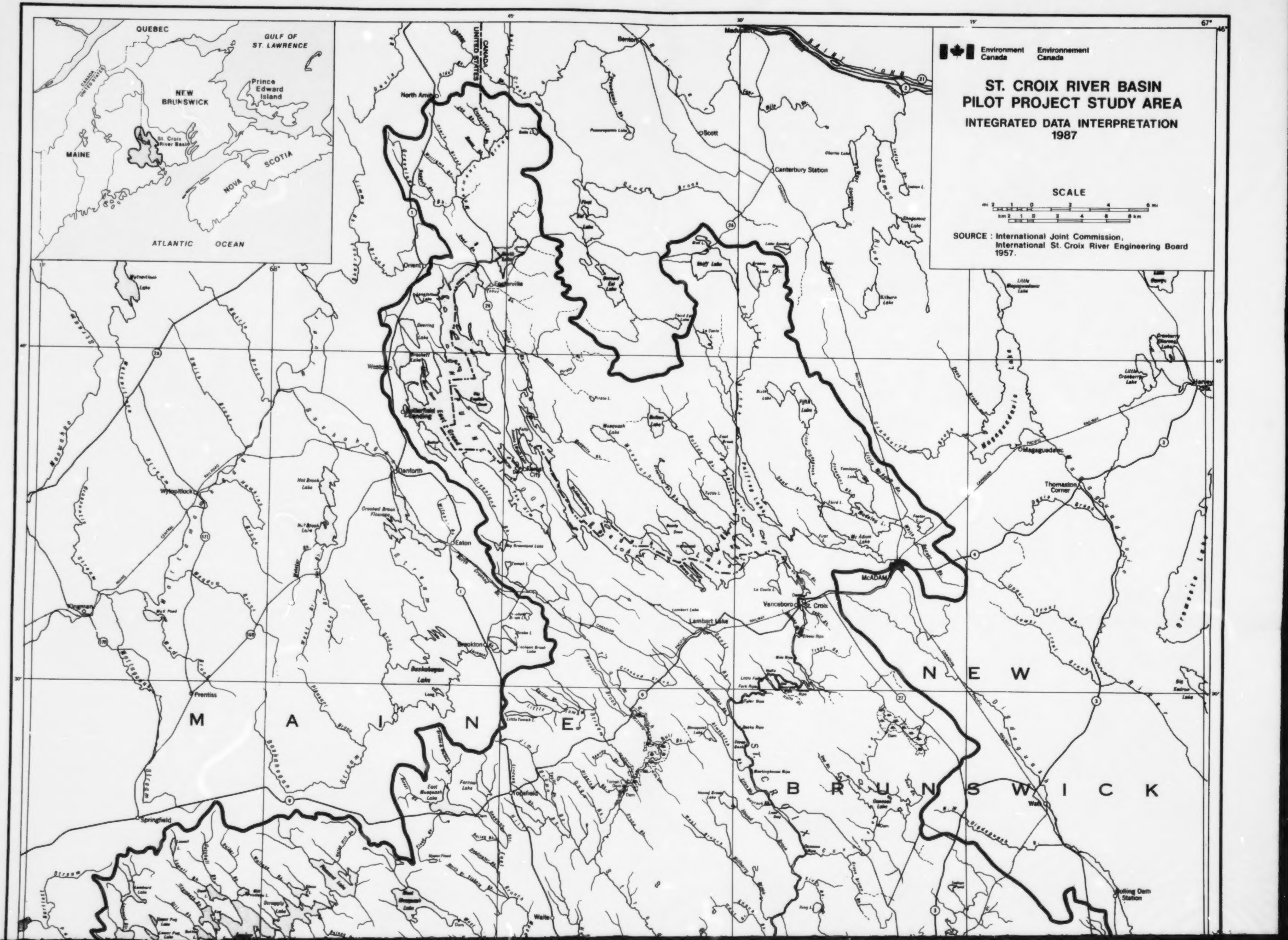

MAINE
NEW BRUNSWICK
ST. STEPHEN
CALAIS
MILLTOWN
MILLTOWN
WOODLAND
McADAM
Vanceboro
Springfield
Prentiss
Brookton
Waite
Princeton
Grand Lake Stream
West Grand Lake
Alexander
Crawford
Meddybemps
Robbinston
Red Beach
Oak Bay
Moores Mills
Rolling Dam Station
MOOSEHORN MIGRATORY WILDLIFE REFUGE
Meddybemps Lake
Crawford Lake
Pocomoonshine Lake
Fifth Machias Lake
Third Machias Lake
Lower Cranberry Lake
Upper Cranberry Lake
Alligator Lake
Passamaquoddy Bay
30'
15'
45°
15'
66°
45'
30'
15'
67°
30'
15'
45°

Figure 3.2



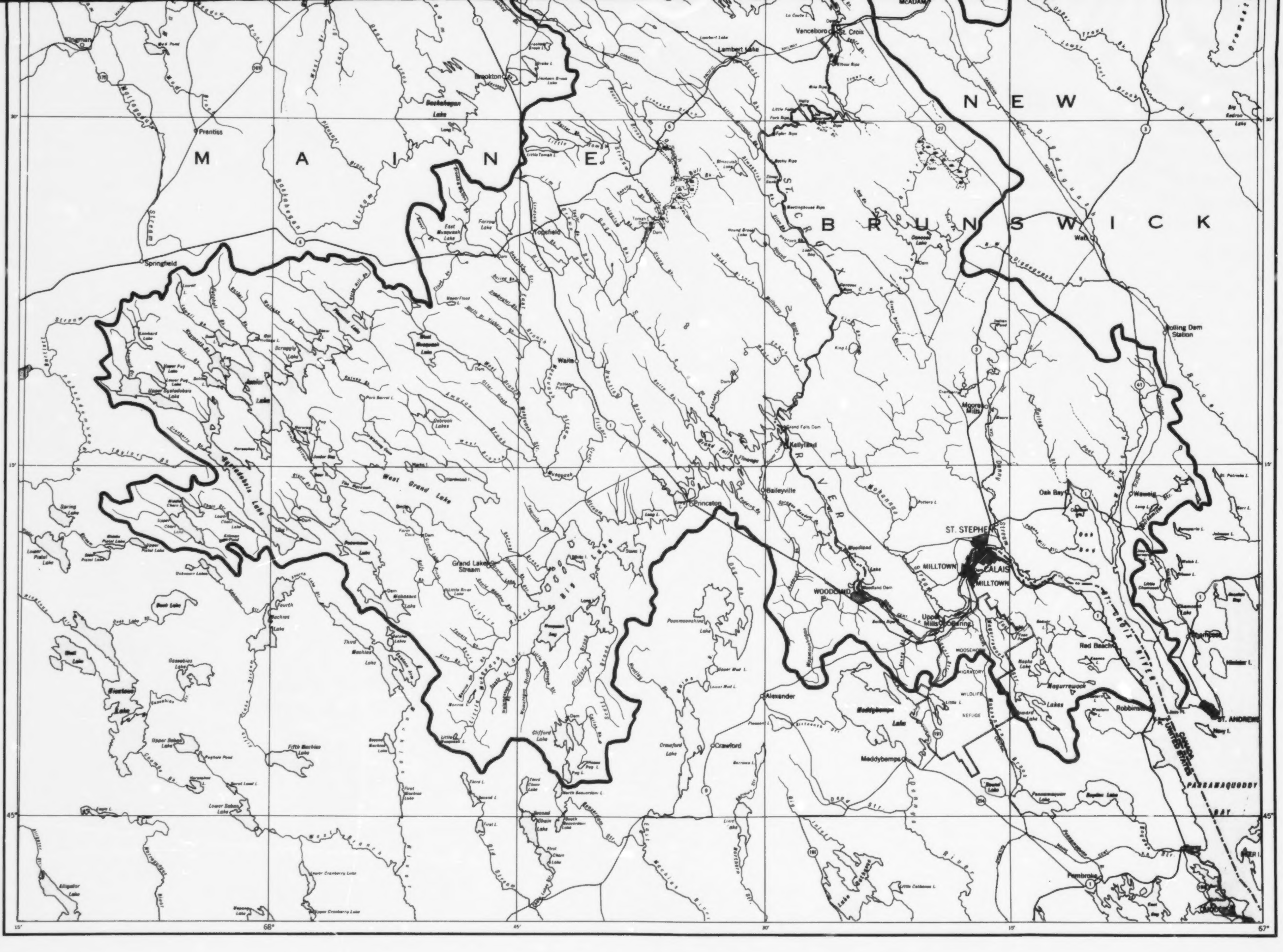
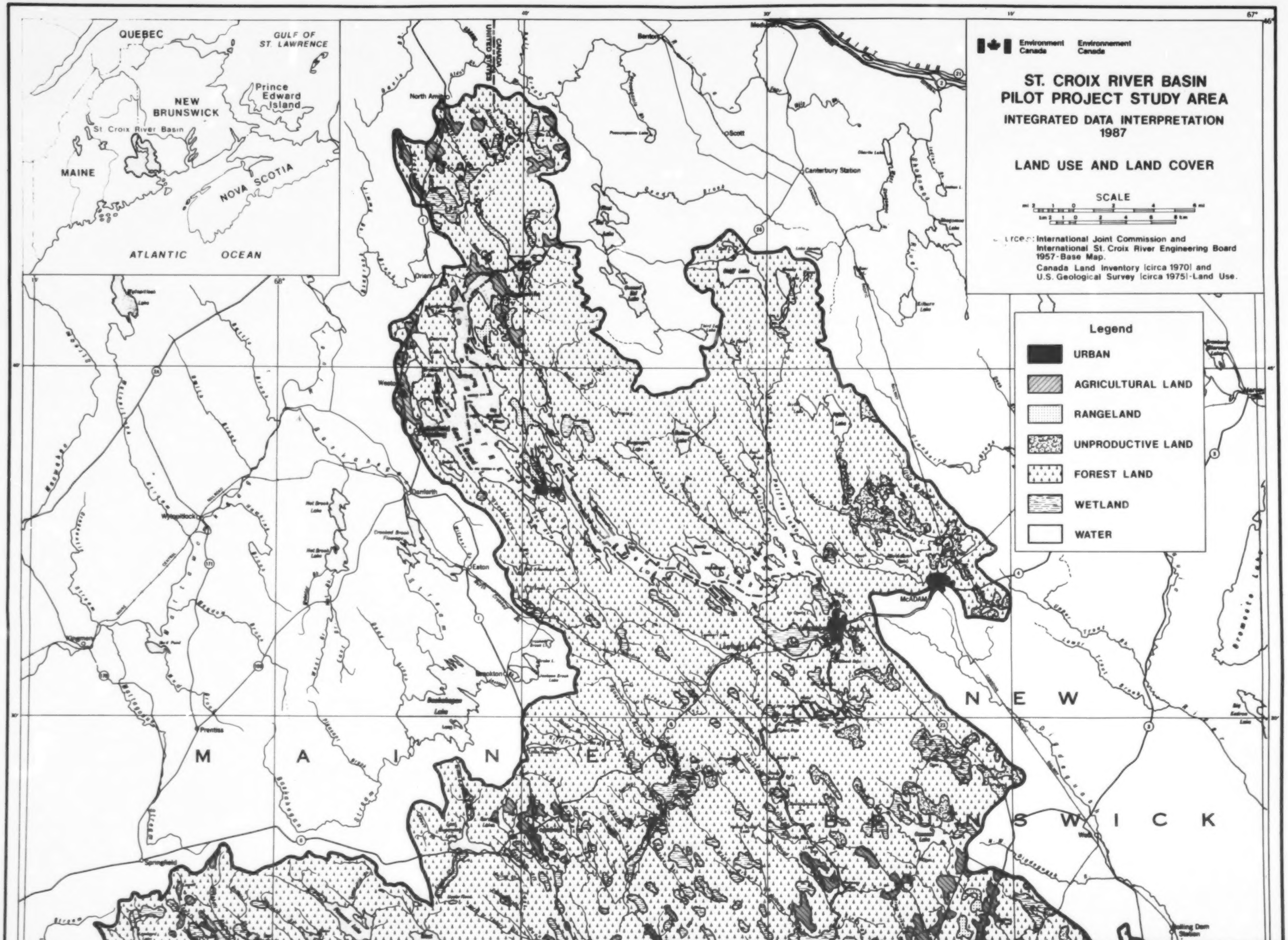

MAINE
NEW BRUNSWICK
ST. CROIX RIVER
Kingman
Prentiss
Springfield
Brookton
Topsfield
Vanceboro
St. Croix
Lambert Lake
Waite
Kellyland
Baileyville
Princeton
Grand Lake Stream
West Grand Lake
Big Lake
WOODLAND
ST. STEPHEN
MILLTOWN
CALAIS
Upper Mills
Moores Mills
Oak Bay
Waweig
Red Beach
Robbinston
ST. ANDREWS
Alexander
Crawford
Meddybemps
Pembroke
Rolling Dam Station
MIGRATORY WILDLIFE REFUGE
PASSAMAQUODDY BAY
CANADA
UNITED STATES
Magurrewock Lakes
Meddybemps Lake
Pocomoonshine Lake
68°
45'
30'
15'
67°
45°

Figure 2.1



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ST. CROIX RIVER BASIN PILOT PROJECT STUDY AREA

INTEGRATED DATA INTERPRETATION
1987

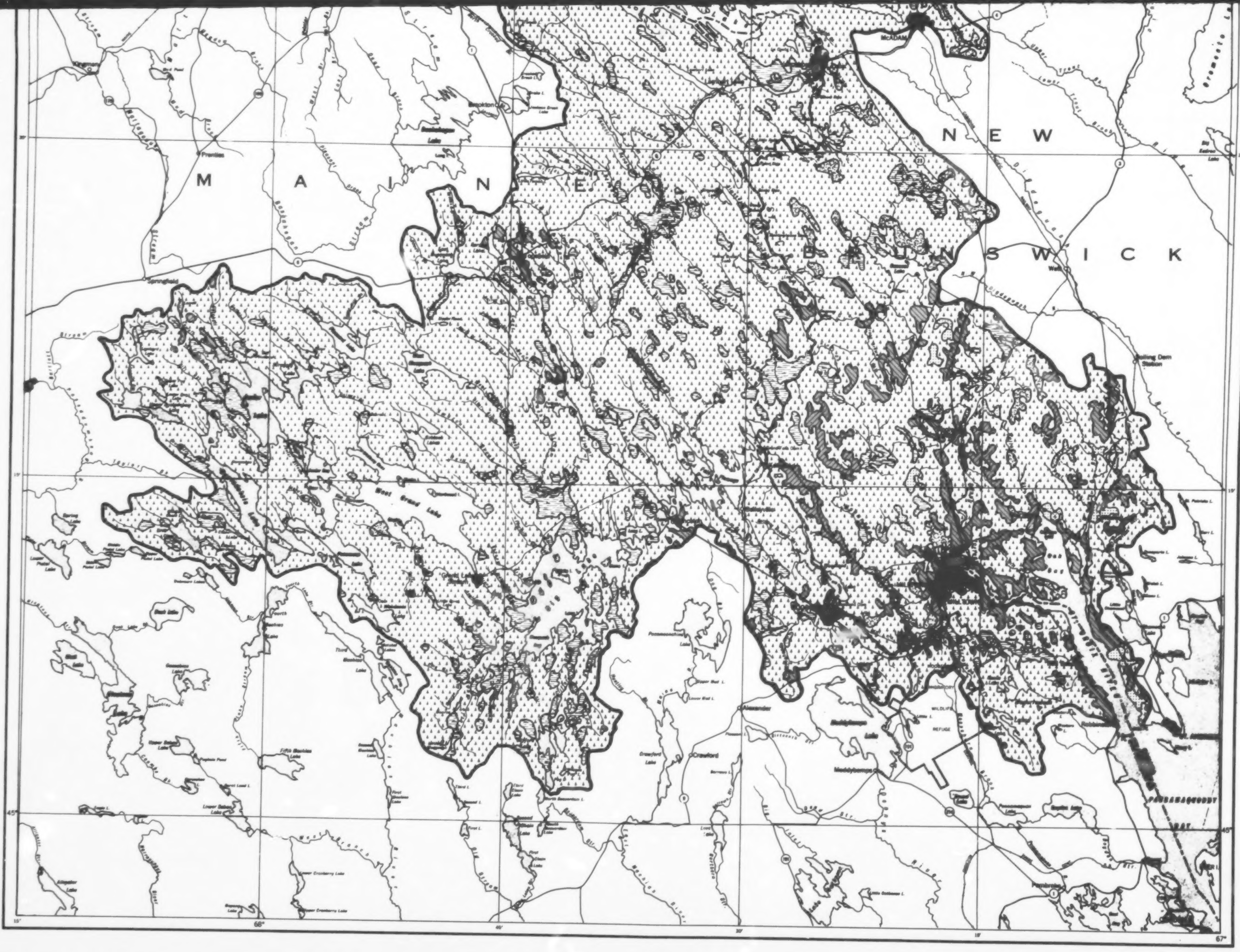
LAND USE AND LAND COVER

SCALE

Sources: International Joint Commission and International St. Croix River Engineering Board 1957-Base Map.

Canada Land Inventory (circa 1970) and U.S. Geological Survey (circa 1975)-Land Use.

mi 2 1 0 2 4 6 mi
km 2 1 0 2 4 6 8 km
Legend
URBAN
AGRICULTURAL LAND
RANGELAND
UNPRODUCTIVE LAND
FOREST LAND
WETLAND
WATER
QUEBEC
GULF OF ST. LAWRENCE
Prince Edward Island
NEW BRUNSWICK
St. Croix River Basin
MAINE
NOVA SCOTIA
ATLANTIC OCEAN
CANADA
UNITED STATES
North Amity
Orient
Weston
Danforth
Wytopitlock
Eaton
Kingman
Brookton
Prentiss
Springfield
Benton
Scott
Canterbury Station
McADAM
M A I N E
N E W
B R U N S W I C K
67°
46°



M A I N E
N E W
B R U N S W I C K
McADAM
Springfield
Prentiss
West Grand Lake
Alexander
Crawford
Meddybemps
WILDLIFE REFUGE
Vanceboro
Princeton
Pembroke
PASSAMAQUODDY
BAY
Baskahegan Lake
Fifth Machias Lake
Nicatous Lake
Pocomoonshine Lake
Gardner Lake
68°
67°
45°
15'
30'
45'
20'

Figure 2.7